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A Study of Estuarine Pollution Problems on A Small Unpolluted Estuary and A Small Polluted Estuary in Florida

by

Thorndike Saville
Principal Investigator

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FOREWORD

This report is a distillation of a number of detailed studies made by a variety of scientists and engineers associated with the Department of Bioenvironmental Engineering at the University of Florida. It is believed to represent an interesting example of interdisciplinary attack on the complex problems involved in a comprehensive study of estuarine pollution. It is perhaps unique in that it comprises studies by the same group and by similar methods on two generally comparable estuaries, one virtually unpolluted and the other heavily polluted. The project was directed and the final report prepared by Dr. Thorndike Saville, the principal investigator.

John E. Kiker, Jr.
Chairman
Department of Bioenvironmental
Engineering
University of Florida

ACKNOWLEDGMENTS

The professional staff and their contributions to the project are listed in the Preface to this report. In addition to the Sections credited to Dr. William H. Morgan in the Preface, special acknowledgment is made of his responsibility for the cartography involved in the preparation for printing of the numerous illustrations in the report, for the processing of the report for printing, and for general assistance. Also, acknowledgment is made of the contributions of Mrs. Daisy Mickler, who has served as secretary of the project since its inception, has prepared the final report for printing, and has performed substantial statistical services during the course of the study.

During the progress of the studies many agencies and individuals unconnected with the project rendered essential and valuable assistance and advice. Scores of technical reports, papers, and communications were contributed which provided guide lines and important background material for the staff. In addition, consultation, basic data, and review of certain sections of the report were received from others. The following list illustrates some of the sources from which cooperation was received.

Federal Agencies

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---

*Formerly Division of Water Supply and Pollution Control, U. S. Public Health Service.

State Agencies

BOARD OF CONSERVATION. *Division of Salt Water Fisheries.* Lt. Cliff Willis, Area Conservation Officer. *Division of Water Resources.* A. O. Patterson, Division Director, and his predecessor, John W. Wakefield.

DEPARTMENT OF HEALTH. *Bureau of Sanitary Engineering.* David B. Lee, Director.

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SOUTHWEST WATER MANAGEMENT DISTRICT. Funding of Stream Gaging stations.

Consultants

Professors Donald J. O'Connor and J. P. Lawler, Manhattan College.
Dr. Harvey F. Ludwig, Consulting Engineer, Engineering Science, Inc.
Dr. F. C. W. Olson of the U. S. Navy Mine Defense Laboratory, Panama City, Florida.

In addition to those mentioned above, Dr. Bostwick H. Ketchum of the Woods Hole Oceanographic Institute kindly arranged for certain special analyses to be performed, and Mr. A. L. Pickens of the Buckeye Cellulose Corporation provided much information in connection with the Fenholloway studies.

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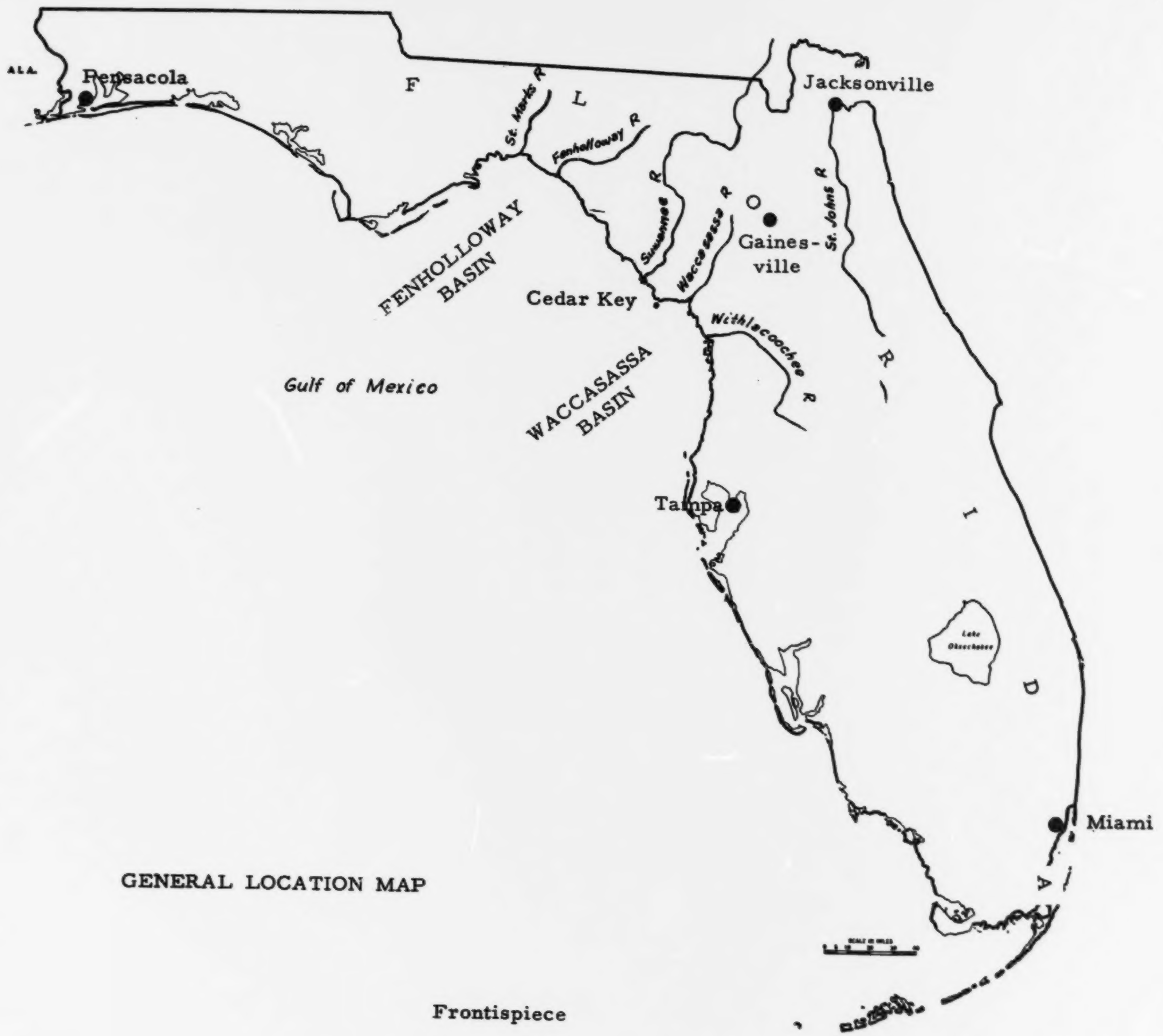

ALA.
Pensacola
F
L
O
R
I
D
A
St. Marks R
Fenholloway R
Suwannee R
Waccasassa R
St. Johns R
Withlacoochee R
Jacksonville
Gaines-
ville
Cedar Key
Tampa
Miami
FENHOLLOWAY BASIN
WACCASASSA BASIN
Gulf of Mexico
Lake Okeechobee

GENERAL LOCATION MAP

Frontispiece

A. GENERAL DESCRIPTION

Selection of the Estuaries

Since the purpose of the project was to identify and interpret as many factors as possible affecting the water quality of an unpolluted and polluted estuary, it was desirable to select estuaries and associated drainage basins which were small enough to enable fairly comprehensive coverage of the various factors with the limited funds available. Similarly, the estuaries should be located within reasonable travel distance from the staff headquarters and the Phelps Environmental Engineering laboratory at Gainesville. These considerations dictated the selection of the estuaries of the Waccasassa and Fenholloway Rivers, both located on the Gulf coast of Florida, as indicated on the frontispiece.

The Waccasassa

The Waccasassa Estuary is located about twelve miles east of the town of Cedar Key, and is actually the most northerly part of Waccasassa Bay. The estuary has been defined for the purposes of this report as that part of Waccasassa Bay which receives drainage only from the Waccasassa River and its tributaries. The drainage area is about 560 square miles and is customarily divided into the Upper and Lower Waccasassa. The Lower Waccasassa is tidal and is shown on Figure A-1, on which the locations of the estuary sampling and tide recording stations are also shown. Figure A-2 indicates the location of all sampling, tide recording, and rainfall stations. Distances between sampling stations are shown on Table A-1. U. S. Geological Survey streamflow installations are located at Sampling Station 2 and on Ten Mile Creek near Lebanon Station in the lower right corner of Figure A-2.

The estuary is a channel in a drowned river valley, terminating near its mouth in a broad, shallow, limestone shelf which slopes gulfward and on which numerous oyster reefs have developed. The oyster reefs are indicated on Plate I and on Figure A-3. The latter figure shows these reefs at low water and indicates the difficulty in navigation and sampling. Much of the same situation exists at the mouth of the Fenholloway. The tide is of the mixed type with a mean range at the estuary mouth of 2.6 feet and a diurnal range of 3.5 feet.

Tidal effects extend for about two miles above Station 1 and about eight miles above the estuary mouth. The Upper Waccasassa, including its principal tributary, the Wekiva River, drains a relatively low, flat terrain consisting of a mantle of Pleistocene sands overlying limestone. The topography is replete with sinks, ponds, and lakes which have been carved out of the limestone by percolation processes. The drainage pattern is, therefore, very irregular. Ground water exists under an artesian head, and there are numerous springs which provide nearly the entire low water flow of the streams.

The Lower Waccasassa below Station 1 flows in a trench cut in the limestone. It and the lower part of its principal tributaries, Otter Creek and Cow Creek, drain largely typical hammock land. The mean range of tide varies from 2.64 feet at Station 6 to 2.55 feet at Station 1, but water elevations are sensitive to wind effects and flood runoff.

There are three small communities on the drainage area, none of which has a sewerage system. There are

Table A-1

DISTANCES OF PRINCIPAL SAMPLING STATIONS FROM STATION 1

Waccasassa

Station	*Miles from Station 1*
1	0
2	0.90
Confluence, Otter Creek	1.30
4	3.40
Confluence, Cow Creek	3.75
6	4.20
7	5.20
8	6.20
9	6.30
10	7.00

NOTE: Station 3 on Otter Creek to Confluence, Otter Creek, 0.65 mi.
Station 5 on Cow Creek to Confluence, Cow Creek, 2.0 mi.

LOCATION OF TIDE STATIONS
AND SAMPLING STATIONS

Lower Waccasassa River and Estuary

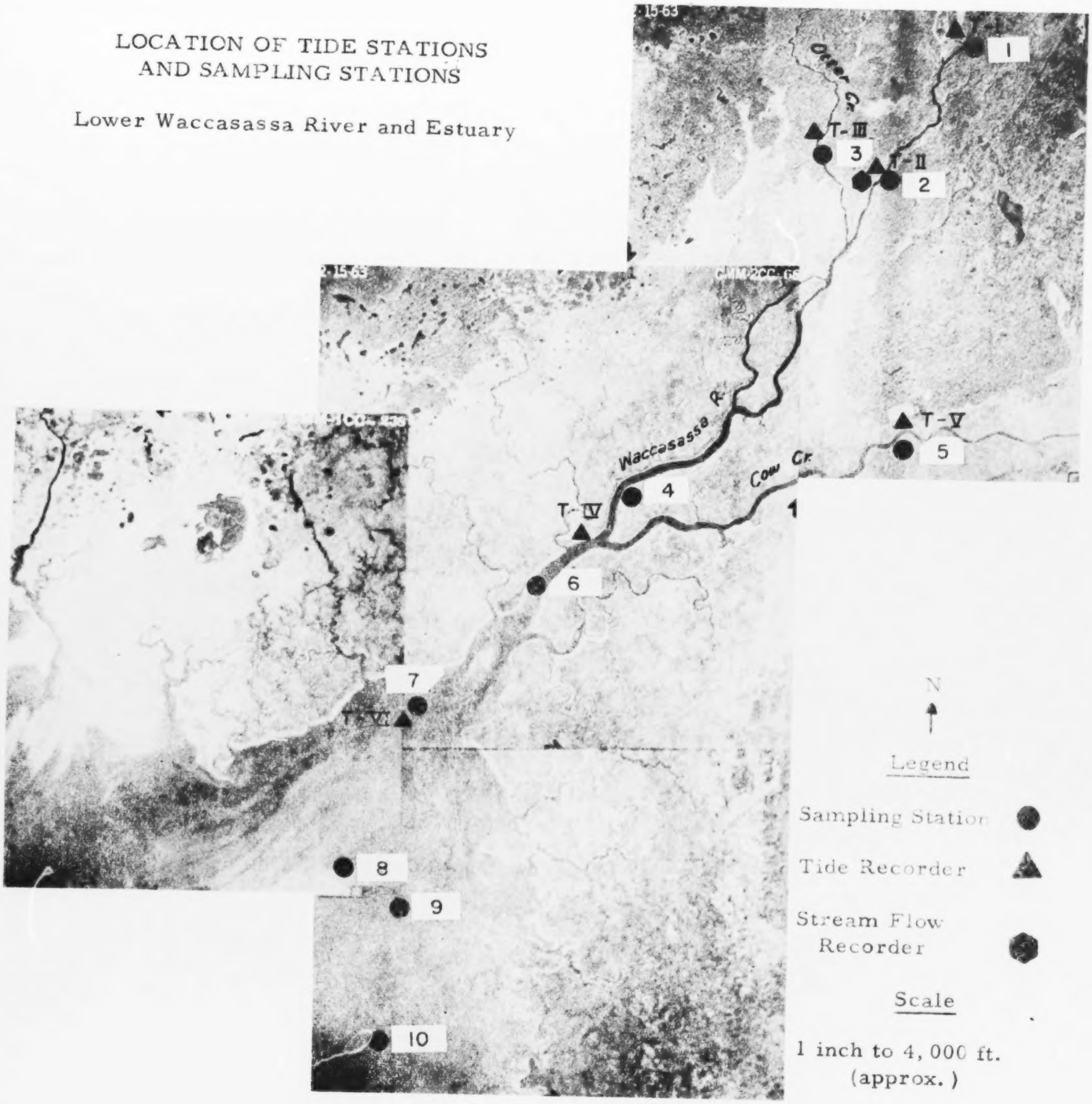

1
Otter Cr.
T-III
3
T-II
2
Waccasassa R.
Cow Cr.
T-V
5
4
T-IV
6
7
T-VI
8
9
10
N
Legend
Sampling Station ●
Tide Recorder ▲
Stream Flow Recorder ●
Scale
1 inch to 4,000 ft. (approx.)

Figure A-1

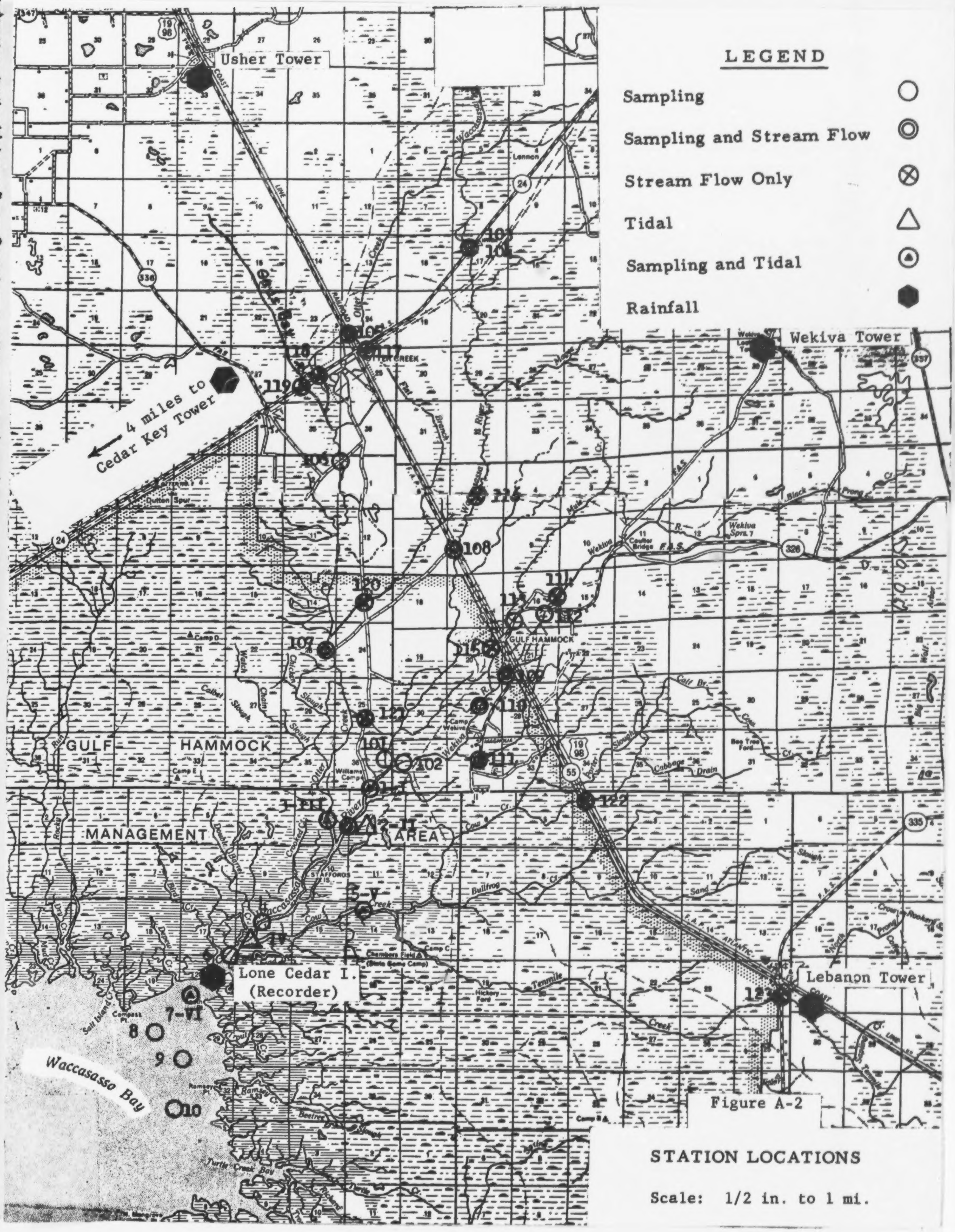

LEGEND
Sampling ○
Sampling and Stream Flow ◎
Stream Flow Only ⊗
Tidal △
Sampling and Tidal
Rainfall ⬢
Usher Tower
Wekiva Tower
4 miles to Cedar Key Tower
Lone Cedar I.
(Recorder)
Lebanon Tower
Waccasasso Bay
GULF HAMMOCK
MANAGEMENT
AREA
GULF HAMMOCK
OTTER CREEK
103
104
105
106
107
108
109
110
111
112
113
114
115
116
117
118
119
120
121
122
123
101
102
1-III
2-II
3-V
IV
7-VI
8
9
10
24
19
98
55
326
336
337
335

Figure A-2

STATION LOCATIONS

Scale: 1/2 in. to 1 mi.

a number of hunting and fishing camps with intermittent occupancy. The population averages less tnan two per square mile. Some livestock and poultry are raised. There is no industrial pollution. On occasion, septic tank overflows and drainage from animal wastes produce minor and local pollution. The Waccasassa Estuary represents about as near an unpolluted and unregulated estuarine system as can be found.

During the course of the Waccasassa study nearly every extreme of flow characteristics was experienced. Sampling was conducted under flow conditions at Station 2 varying from 55 to 3540 cubic feet per second. A total of 12,621 chemical analyses and 2,390 bacteriological analyses were made. These, together with data from rainfall, stream gaging, and tide recording stations, represent the basic data from which the several sections of the report have been prepared.

The Fenholloway

The Fenholloway Estuary is located near the northernmost part of peninsula Florida, about 80 miles northwest of the Waccasassa Estuary. Climatic conditions and the physiography of the drainage basins of the two estuaries are similar, but in other respects they are quite different. The Waccasassa Estuary empties into a distinct embayment, while that of the Fenholloway does not. The Fenholloway Estuary is smaller, narrower, and has a steeper hydraulic gradient than the Waccasassa. The Fenholloway is heavily polluted and the Waccasassa is not. The drainage area of the Fenholloway is about 330 square miles compared to about 560 square miles for the Waccasassa. These differences are naturally reflected in the results of the studies of the two estuaries.

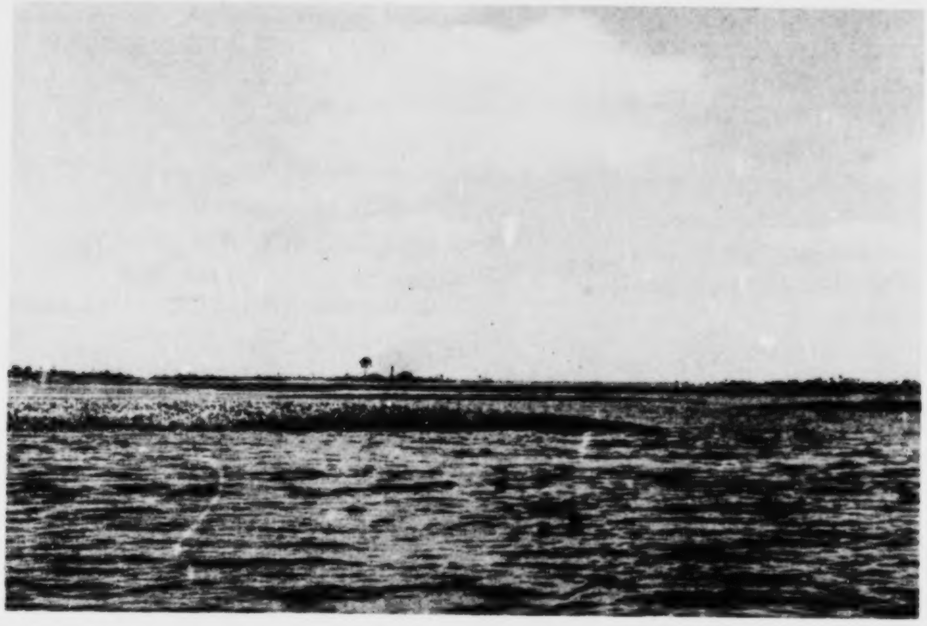
Figure A-4 is an aerial view of the Fenholloway Estuary and tidal portion of the river. Mean and diurnal ranges of tide at the mouth of the estuary are respectively 2.4 and 3.3 feet. Mean range of tide decreases to 1.87 feet at Station F-106 (Hicks Camp). The extent of tidal influence on the Fenholloway is about 3.8 miles as compared with about 8 miles on the Waccasassa, due to the greater slope and different configuration of the Fenholloway.

Table A-2

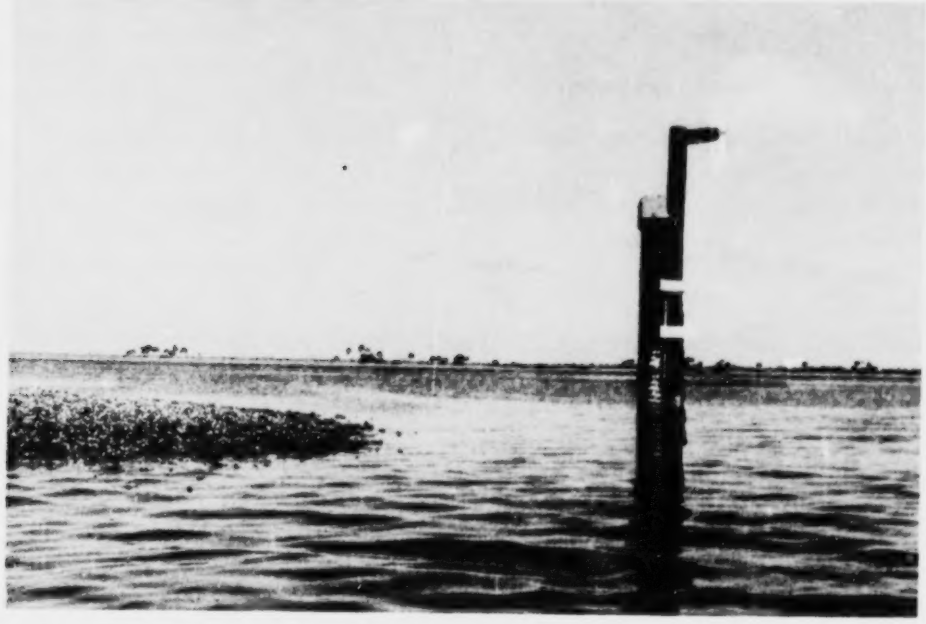
DISTANCES TO SAMPLING STATIONS

Fenholloway

Station	*Miles from Mouth Station F-1*	*Miles from Station F-101*
F-101	28.1	0
F-1011	22.7	5.4
F-102	21.1	7.0
F-103	13.4	0.9 above mouth of Spring Creek
F-104	12.8	15.3
Mouth of Spring Creek	12.5	15.6
Tide Limit	4.1	24.1
F-106	2.4	25.7
F-1061	1.5	26.6
F-107	0.6	27.5
F-1	0	28.1
F-2	2.0	30.1
F-10	2.5	30.6
F-6	3.9	32.0
F-9	5.2	33.3
F-3	5.2	33.3
F-8	5.4	33.5
F-7	6.4	34.5
F-5	7.0	35.1
F-4	7.7	35.8
F-11	9.4	37.5



a. Oyster bars at low tide near Sampling Station 7



b. Tide recorder T-V1

Figure A-3

Typical Low Tide Conditions Near Mouth of Waccasassa Estuary

Figure A-5 indicates the location of the sampling, tide recording, and stream gaging stations. Table A-2 gives the distances between stations. The principal pollution of the river comes from the wastes discharged by the Buckeye Cellulose plant (Figure A-6) at Foley. The effluent from the sewage treatment plant at Perry (population about 8500) discharges into Spring Creek about five miles above its confluence with the Fenholloway. A crab processing plant disposes of its wastes in the Fenholloway in the vicinity of Station F-104, and there is moderate contribution of domestic wastes from other sources.

The influence of the kraft mill wastes introduced at Station F-1011 is pronounced. BOD and COD are high and DO is generally absent until the river becomes tidal in the vicinity of Station F-106, except during mill shutdown or high streamflow. These effects persist in less degree throughout the estuary, so that routine analyses and studies of dilution and diffusion were carried out into the shallow waters of the adjacent Gulf. Significant changes in various parameters of pollution occur also in the twenty miles of river from Station F-1011 to the head of the estuary. There were 8,942 chemical and 702 bacteriological analyses made in the course of the study.

As in the case of the Waccasassa, sampling covered substantial variations of flow, in this case from 240 to 1750 cubic feet per second near the head of the estuary. Hurricane Dora passed over the drainage area during the study.

The Nearshore Gulf

This study deals with factors influencing or likely to influence pollution on (a) a virtually unpolluted estuary, that of the Waccasassa, and (b) a highly polluted estuary, that of the Fenholloway. However, many of the factors to be considered exist outside of the estuary or tidal river. The character of the drainage area and the sources of fresh water flow and of pollution constitute important factors above the head of the estuary. Tidal phenomena and nearshore conditions in the Gulf involve factors beyond the mouth of the estuary. Hence a comprehensive study of pollution problems must consider factors influencing the waters both discharged to and discharged from the estuary, as well as waters of the estuary itself. Consequently the investigations reported herein embrace not only the waters of each estuary but also, to the extent necessary, the headwaters and the waters of the nearshore Gulf.

General

This report represents a rather drastic condensation of the section reports mentioned in the Preface. Therefore it is hoped that those who find any parts of the report inadequate or inaccurate will send for the applicable section report before reaching final conclusions. To have printed all of the section reports would have required a volume more than twice the size of the present report.

PART I

THE WACCASASSA

B. GEOMORPHOLOGY AND ECONOMY

Geomorphology

General Description. The Waccasassa River Basin (Plate I) lies between the watersheds of the Withlacoochee and Suwannee Rivers. It comprises approximately 560 square miles. The northern one-third of the basin is largely without surface drainage, except during periods of very heavy runoff, and is marked by a series of swamps, lakes, and ponds in a wide valley. South from Blue Spring the area is drained by the Waccasassa River and its principal tributaries, the Wekiva River, Otter Creek, Cow Creek, and smaller streams. The littoral area is low and marshy for an average of one to two miles inland; then backed principally by hammock land. There are no sandy beaches.

The northern and eastern sections, where a few elevations reach 100 feet above sea level, have poorly defined drainage patterns due to subterranean flow through the underlying porous and cavernous limestone and the low divides. The area is replete with collapsed solution cavities in the limestone forming "sinks." In times of low precipitation they may be dry, becoming ponds as ground water levels rise, and overflowing to surface drainage under conditions of heavy precipitation. The land surface slopes to the west and southwest, and a large portion of the lower basin consists of a salt marsh.

The nature of the relief, however, is not the only factor responsible for surface water features. There is an artesian ground water head near the shoreline. In several instances, artesian springs such as Wekiva Spring and Blue Spring have been created by the percolation of rainwater downward through the limestone, dissolving vertical chimneys to the artesian aquifer, after which the surface covers have caved in. These artesian springs contribute a major portion of the fresh water flow from the river system during periods of low water.

Geology and Physiography. The Waccasassa Basin lies within the Coastal Plain Province. Vernon (1951) has subdivided Florida into four physiographic groups. The Waccasassa Basin is included in his River Valley Lowlands and Terraced Coastal Lowlands. The coastal lowlands comprise about ninety per cent of the basin and consist of marine terraces which were the bottoms of the seas during the Pleistocene Epoch in the United States.

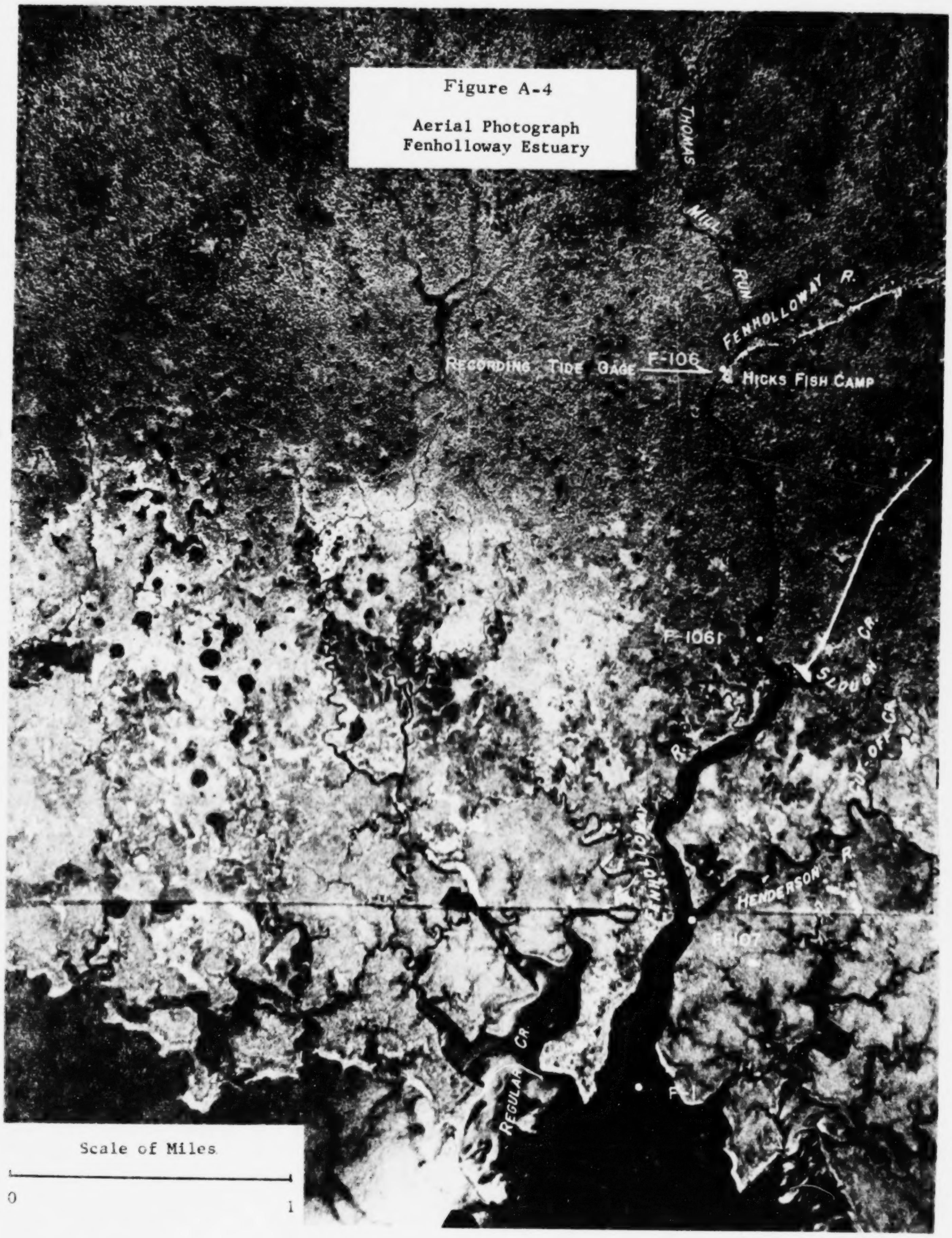


Figure A-4

Aerial Photograph
Fenholloway Estuary

THOMAS
MILL
RUN
FENHOLLOWAY R.
RECORDING TIDE GAGE
F-106
HICKS FISH CAMP
F-1061
SLOUGH CR.
FENHOLLOWAY R.
GULF OF CA
HENDERSON R.
F-107
REGULAR CR.
F-1
Scale of Miles
0
1

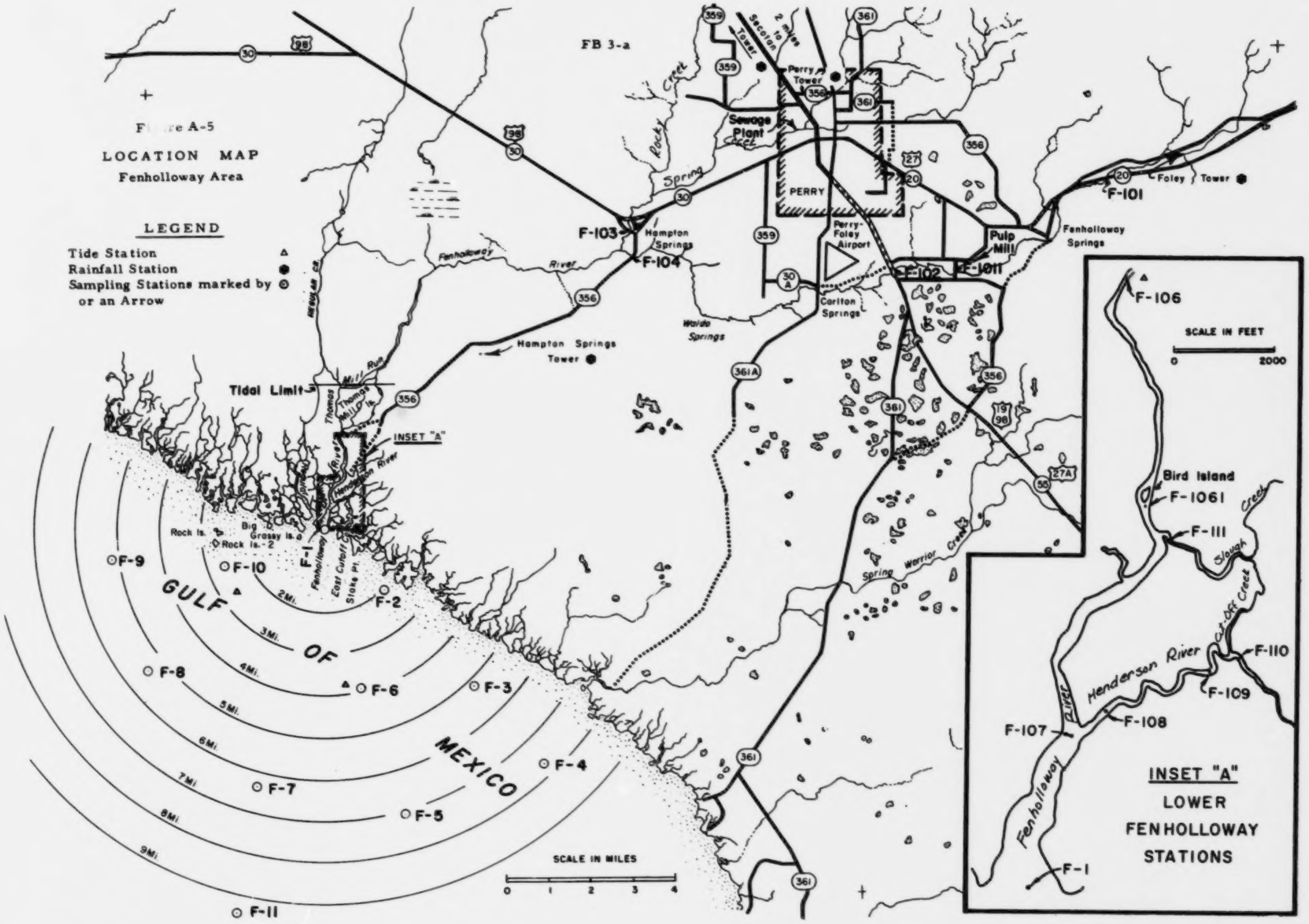
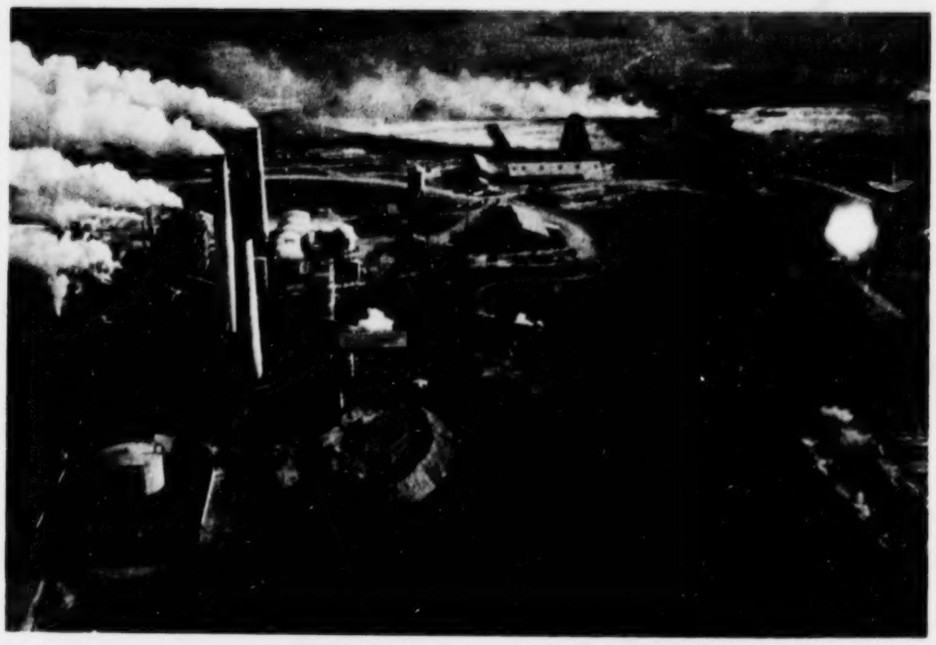
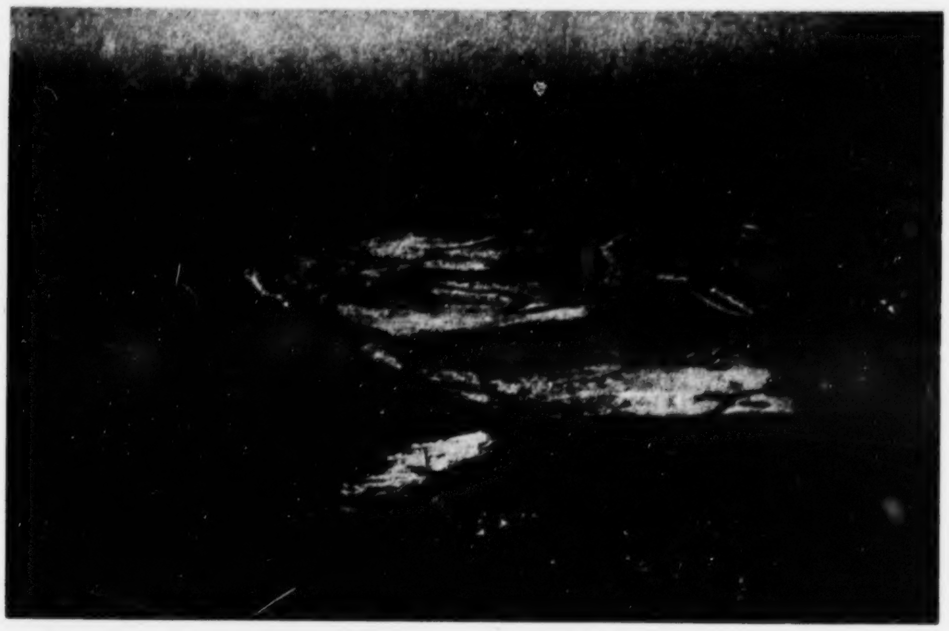


Figure A-5
LOCATION MAP
Fenholloway Area

FB 3-a
LEGEND
Tide Station △
Rainfall Station ●
Sampling Stations marked by ⊙ or an Arrow
GULF OF MEXICO
F-1
F-2
F-3
F-4
F-5
F-6
F-7
F-8
F-9
F-10
F-11
F-101
F-102
F-103
F-104
F-1011
2Mi.
3Mi.
4Mi.
5Mi.
6Mi.
7Mi.
8Mi.
9Mi.
SCALE IN MILES
0 1 2 3 4
Tidal Limit
INSET "A"
Rock Is.
Rock Is.-2
Big Grassy Is.
East Cutoff
Stake Pt.
Fenholloway River
Henderson River
Thomas Mill Run
Spring Creek
Rocky Creek
Spring Warrior Creek
Hampton Springs
Hampton Springs Tower
Waldo Springs
Carlton Springs
Perry-Foley Airport
PERRY
Perry Tower
2 miles to Secotan Tower
Sewage Plant
Pulp Mill
Fenholloway Springs
Foley Tower
30
98
356
359
361
361A
30A
27
27A
19
20
INSET "A"
LOWER FENHOLLOWAY STATIONS
SCALE IN FEET
0 2000
F-106
Bird Island
F-1061
F-111
Slough Creek
Cut-Off Creek
F-110
F-109
F-108
F-107
Henderson River
Fenholloway River
F-1

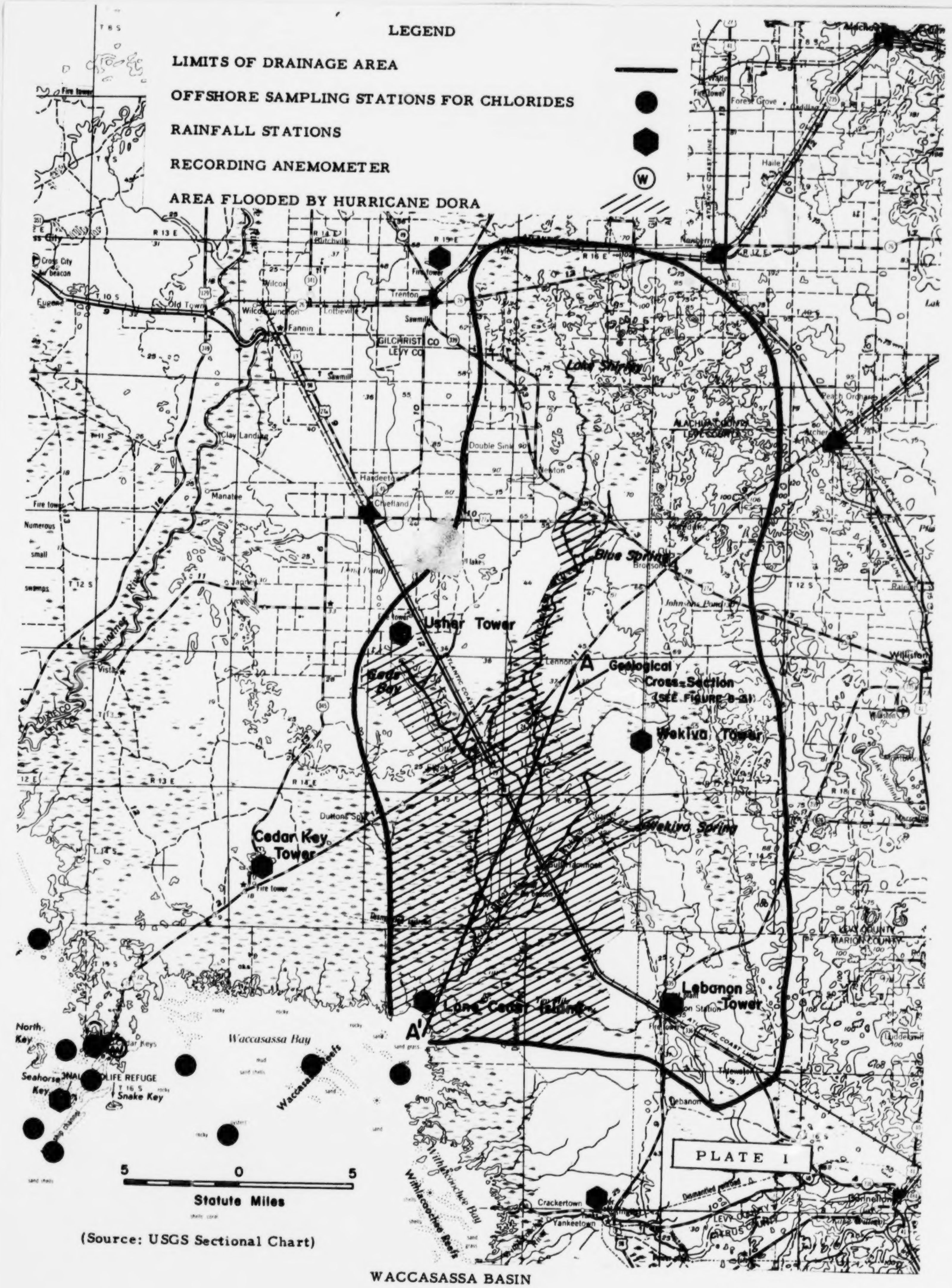


a. Aerial view of Buckeye Cellulose Mill looking North.



b. Aerial view of Mill lagoon looking South toward Station F-1011.

Figure A-6


LEGEND
LIMITS OF DRAINAGE AREA
OFFSHORE SAMPLING STATIONS FOR CHLORIDES ●
RAINFALL STATIONS ⬢
RECORDING ANEMOMETER Ⓦ
AREA FLOODED BY HURRICANE DORA ▨
Trenton
Chiefland
Lake Shipley
Double Sink
Blue Spring
Bronson
Usher Tower
Gulf Hammock
A
Geological Cross-Section (SEE Figure b-a)
Wekiva Tower
Wekiva Spring
Cedar Key Tower
A'
Long Cabin Island
Lebanon Tower
Waccasassa Bay
Waccasassa Reefs
North Key
Seahorse Key
Snake Key
Cedar Keys
Withlacoochee Reefs
Crackertown
Yankeetown
LEVY COUNTY
MARION COUNTY
CITRUS COUNTY
PLATE I
5
0
5
Statute Miles

(Source: USGS Sectional Chart)

WACCASASSA BASIN

The physiography of the region is shown on Figure B-1, on which the Waccasassa drainage area has been delineated. A geological cross section paralleling the Waccasassa is shown on Figure B-2 and its location is indicated on Plate I by the line A-A'. Over the lower two-thirds of this profile the mantle of Pleistocene sediments is quite thin and consists in many places of carbonaceous sands, the organic material of which forms a relatively impervious layer locally called "hardpan." This hardpan facilitates a more rapid runoff of surface waters than customarily found in sandy mantles. Heavy rainfall saturates the mantle to the hardpan and creates swampy conditions with flooding and runoff to the nearest streams.

The Coast. The coastline bordering the study area forms a part of a larger littoral zone extending from Anclote Keys on the south to Apalachee Bay on the northwest which is characterized by features unique in the United States. This a tidal marsh area and the shoreline is the muddy prograding edge of the marsh in most instances, the seaward side of which is at the ordinary high water line. The limerock underlying the hammock land back of the marshes extends itself as fingers and islands into the marshy area, and there are many meandering streams. There are no sandy beaches. Some sediment, but virtually no sand, is carried by the Waccasassa and other streams in this littoral zone, and there are no prevailing longshore currents to bring sand from other sources. This entire stretch of coast is underlain at shallow depth by limestone forming a broad shallow shelf. Much of any substantial wave energy is dissipated well offshore against the limerock platform. This permits whatever sediments that do reach the coast to be deposited and the tidal marsh to prograde. The shallow water and the funnel-like physiography of the Waccasassa Estuary, however, are conducive to the formation of storm surges in connection with strong and persistent onshore winds. These phenomena are discussed later under D. HYDROLOGY and E. TIDAL PHENOMENA.

The River System. The Waccasassa River has its source in Lake Shirley (Plate I) but can be classified as perennial only below Blue Spring. South of Stations 103-104 (Figure A-2) it flows through a limestone trench which it has cut into the underlying rock. It continues through a swampy region, meandering until its confluence with the Wekiva a short distance above Station 1. The streams are subject to tidal influences at this point, which may be considered the head of the estuary. Below this point the stream is locally referred to as the Lower Waccasassa.

The Wekiva River has its source in Wekiva Spring, which is artesian in character and has a discharge averaging about 40 million gallons per day or 62 cubic feet per second. It flows west and southwest until it enters a swampy braided stream area and has a number of shallow channels which ultimately form again into the main stream of the Wekiva River above its confluence with the Upper Waccasassa.

Otter Creek and Cow Creek are the two chief tributaries of the Waccasassa in its estuary portion. Both are tidal in the lower reaches, and neither contributes much fresh water flow to the estuary except in periods of above average rainfall.

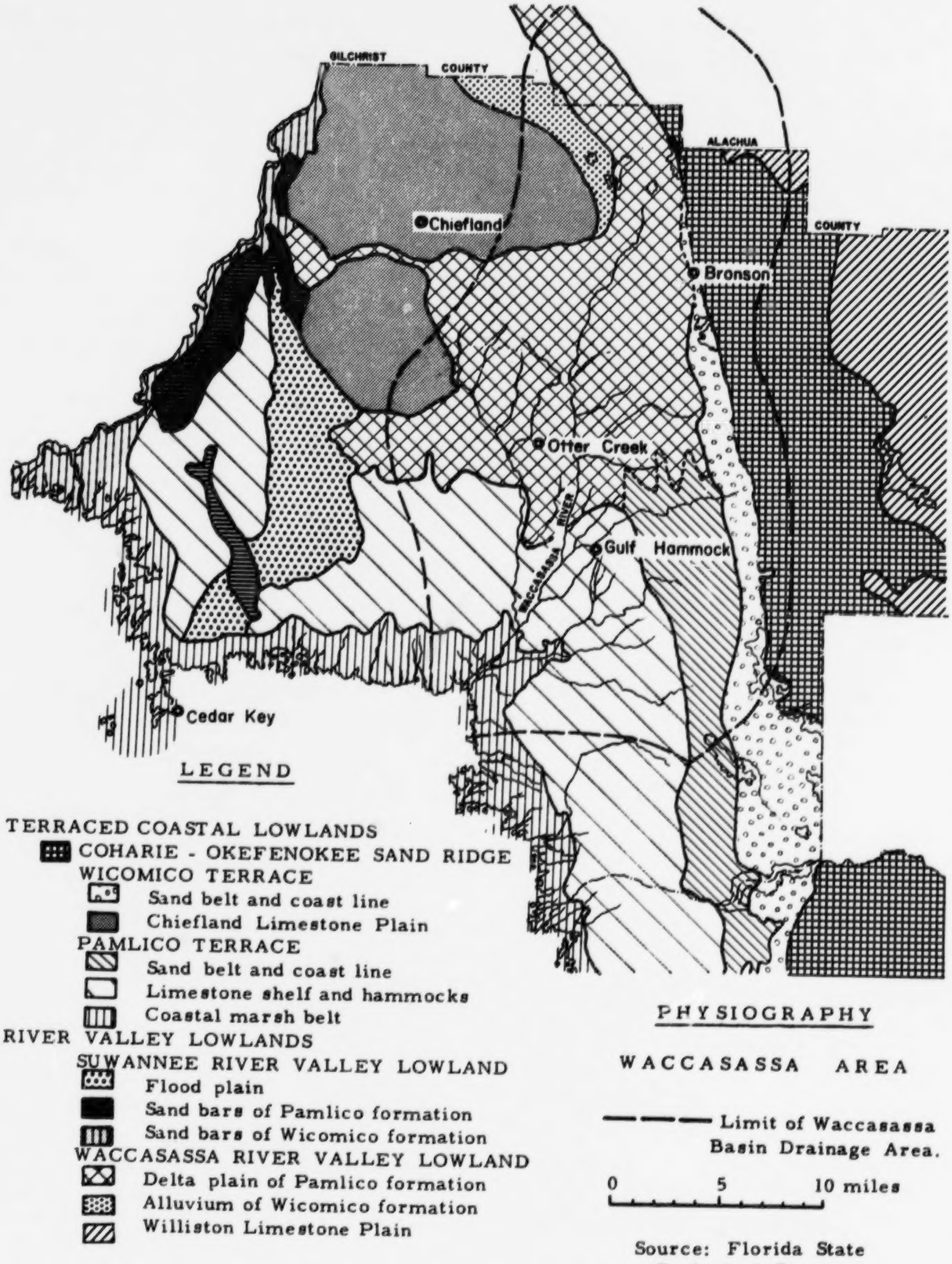
Climate. The climate is temperate, average temperatures ranging from 58°F in winter to 81°F in summer. Extremes range from 13°F to 101°F. The growing season in the coastal zone is about 315 days, while that in the higher inland area is about 290 days. Average annual rainfall varies from about 52 inches along the coast to over 70 inches over most of the Waccasassa drainage area. The area is subject to occasional tropical storms which produce a very high rainfall and create storm surges into the estuary. Details are given under D. HYDROLOGY.

Economy

Land Resources. The Waccasassa Basin encompasses some 360,000 acres of which about two-thirds is cut-over land forested with several types of pine, gum, cypress, and some hardwoods. Much of this land is owned by various lumber and paper companies and has been utilized as a Wild Life Management Area. Recently about 132,000 acres has been purchased by the Georgia-Pacific Corporation which has plans to conduct a reforestation program. This may affect the use of the area for wild life management purposes. On the Wekiva River there are about 1500 acres of valuable crop and pasture land.

Water Resources. The Waccasassa Basin has an adequate supply of good quality water both from ground and surface sources during periods of average or above average precipitation. Since virtually all fresh water in Levy County is derived directly from precipitation which has fallen locally or in adjacent counties, there will be periods in times of drought when conservation of water or emergency irrigation measures are needed. Most of the wells in the basin are shallow, from ground water operating under water-table conditions. It is not unusual for some of these wells to dry up during periods of prolonged drought. The entire basin is primarily a discharge area; the supply of artesian water coming from recharge areas as distant as Clay and Bradford Counties fifty to seventy miles to the northeast. Salt water intrusion is not presently a problem but could become one if the coastal region is developed by dredging and filling. The principal water problem at present is flooding during periods of excessive rainfall.

Present and Potential Economy. The economy of the


GILCHRIST COUNTY
ALACHUA COUNTY
Chiefland
Bronson
Otter Creek
Gulf Hammock
WACCASASSA RIVER
Cedar Key
LEGEND
TERRACED COASTAL LOWLANDS
COHARIE - OKEFENOKEE SAND RIDGE
WICOMICO TERRACE
Sand belt and coast line
Chiefland Limestone Plain
PAMLICO TERRACE
Sand belt and coast line
Limestone shelf and hammocks
Coastal marsh belt
RIVER VALLEY LOWLANDS
SUWANNEE RIVER VALLEY LOWLAND
Flood plain
Sand bars of Pamlico formation
Sand bars of Wicomico formation
WACCASASSA RIVER VALLEY LOWLAND
Delta plain of Pamlico formation
Alluvium of Wicomico formation
Williston Limestone Plain
Limit of Waccasassa Basin Drainage Area.
0
5
10 miles

PHYSIOGRAPHY

WACCASASSA AREA

Source: Florida State Geological Survey

Figure B-1

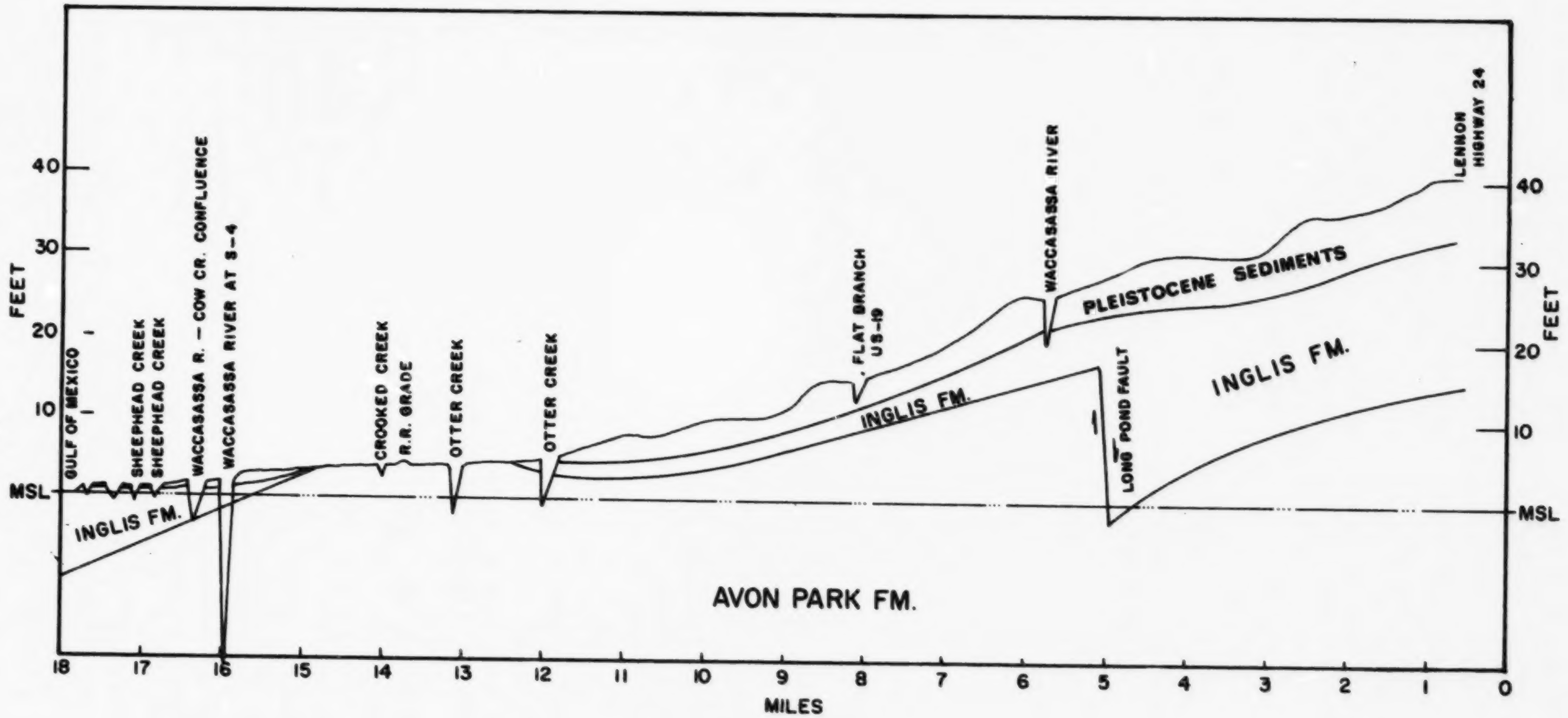

FEET
40
30
20
10
MSL
GULF OF MEXICO
SHEEPHEAD CREEK
SHEEPHEAD CREEK
WACCASASSA R. — COW CR. CONFLUENCE
WACCASASSA RIVER AT S-4
CROOKED CREEK
R.R. GRADE
OTTER CREEK
OTTER CREEK
FLAT BRANCH
US-19
WACCASASSA RIVER
LENNON
HIGHWAY 24
PLEISTOCENE SEDIMENTS
INGLIS FM.
INGLIS FM.
INGLIS FM.
LONG POND FAULT
AVON PARK FM.
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
MILES

Figure B-2

Geological Cross-Section
Lennon to Gulf of Mexico

(Line A-A^1, Plate I)

Waccasassa Basin and of Levy County, in which most of the basin lies, has always been based primarily upon forestry and agriculture, with some commercial and sport fishing. The population of Levy County has ranged from 10,000 to 12,000 over the past few years, mostly centered in a few small towns, none of which has a sewerage system as yet. Growth of light industry will probably continue at a rather slow rate. The extension of the Intracoastal Waterway from St. Marks along the west coast to the western terminus of the Cross Florida Barge Canal would have a beneficial effect upon the economy of the region. Local communities and the Southwest Florida Water Management District have sound plans for conservative development.

It is too early to state at this time (March 1966) just how much the Waccasassa Basin will be affected by the future operations of the Georgia-Pacific Corporation. The company will operate a pine plywood mill and hardwood saw mill about one mile north of the town of Chiefland, which is just outside of the Waccasassa Basin. They will employ several hundred persons locally and will have an annual payroll of around two million dollars. Operations will commence in late 1966.

C. HYDROGRAPHY

The Waccasassa Estuary is defined in this report as extending from a line joining Compass and Ramsey Points on the south to the confluence of the Waccasassa and Wekiva Rivers on the north. (See Plate II and Figure C-1.) The southern boundary marks the southernmost extent of appreciable fresh water contribution from the Waccasassa system and the northern boundary is the approximate limit of tidal influence.

Since no hydrographic data were available for the estuary, a survey was made involving 51 cross sections and several longitudinal profiles. These were made by echo sounder and sounding rod. Data were determined from six tide level recorders located as shown in Figures C-1 and A-2.

On Figure C-2, Cross Sections 1, 2, and 3 are actually profiles (Plate II) taken along with Cross Section 4 at the mouth of the estuary to show the general characteristics of the lower estuary and bay. These cross sections and profiles indicate a generally shallow bay bottom with channels cut in the limestone plain before the region was submerged by a rise in sea level. The average depth of -5 feet MLW as one leaves the estuary (CS-4) may readily be reduced considerably by prolonged offshore winds. Cross Sections 6, 7, and 22 (Figures C-2 and C-3) indicate the deeper channels cut in the underlying rock as one proceeds upstream.

Figure C-3 shows a profile of the estuary from Cross section 21 to Cross Section 35, a distance of some four miles. This is particularly illuminating as indicating the numerous solution cavities, some extending to over twenty feet below mean low water. A similar situation exists on Cow Creek. These irregularities of the bottom make navigation and sampling difficult and produce substantial functional resistance to flow. Figures C-2 and C-3 inclusive also depict the general reduction in cross-section areas with distance from the estuary mouth. The hydrographic surveys enabled estimates to be made of the tidal prism and were used in connection with other sections of this report.

D. HYDROLOGY

A general description of the Waccasassa Basin is presented in the two preceding sections and includes the drainage pattern, physiography, soils, geology, and other physical characteristics. The character of the vegetation, soils, and geology as affecting streamflow are also described. Streamflow is important in the present investigation with relation to estimates of the fresh water dilution it affords in the estuary, its potential for carrying pollution to the estuary, and public health hazards from flooding. Unfortunately, continuous streamflow records suitable for these purposes did not exist until much of the field work and report drafting had been completed. Such records and measurements as are available are discussed later in this section. Because of the paucity of streamflow measurements, recourse was had to rainfall records to interpret various aspects of streamflow.

Rainfall

No long-term rainfall records exist at any stations within the Waccasassa Basin. There is a long-term record at Cedar Key (Plate I) but it was not suitable for use in this study. There are records of daily, monthly, and annual rainfall at four fire towers within the drainage area operated by the Florida Forest Service since 1959. In addition, two recording rainfall stations were installed and operated for the duration of the study at Lone Cedar Island and on Seahorse Key. The location of all of these stations is shown on Plate I and all but the last are indicated on Figure A-2. Analysis of the records at these stations and at the nearest long-term stations at Gainesville and at Cross City indicated that the average rainfall at the four fire tower stations probably gave the best indication of rainfall on the drainage area and that the average rainfall for the years 1959-63 inclusive was reasonably representative of the long-term rainfall. Hence the records from only these four stations were used in this report.

Table D-1 gives the estimated long-term average monthly and annual rainfall on the drainage area and also the average monthly rainfall and departures from the

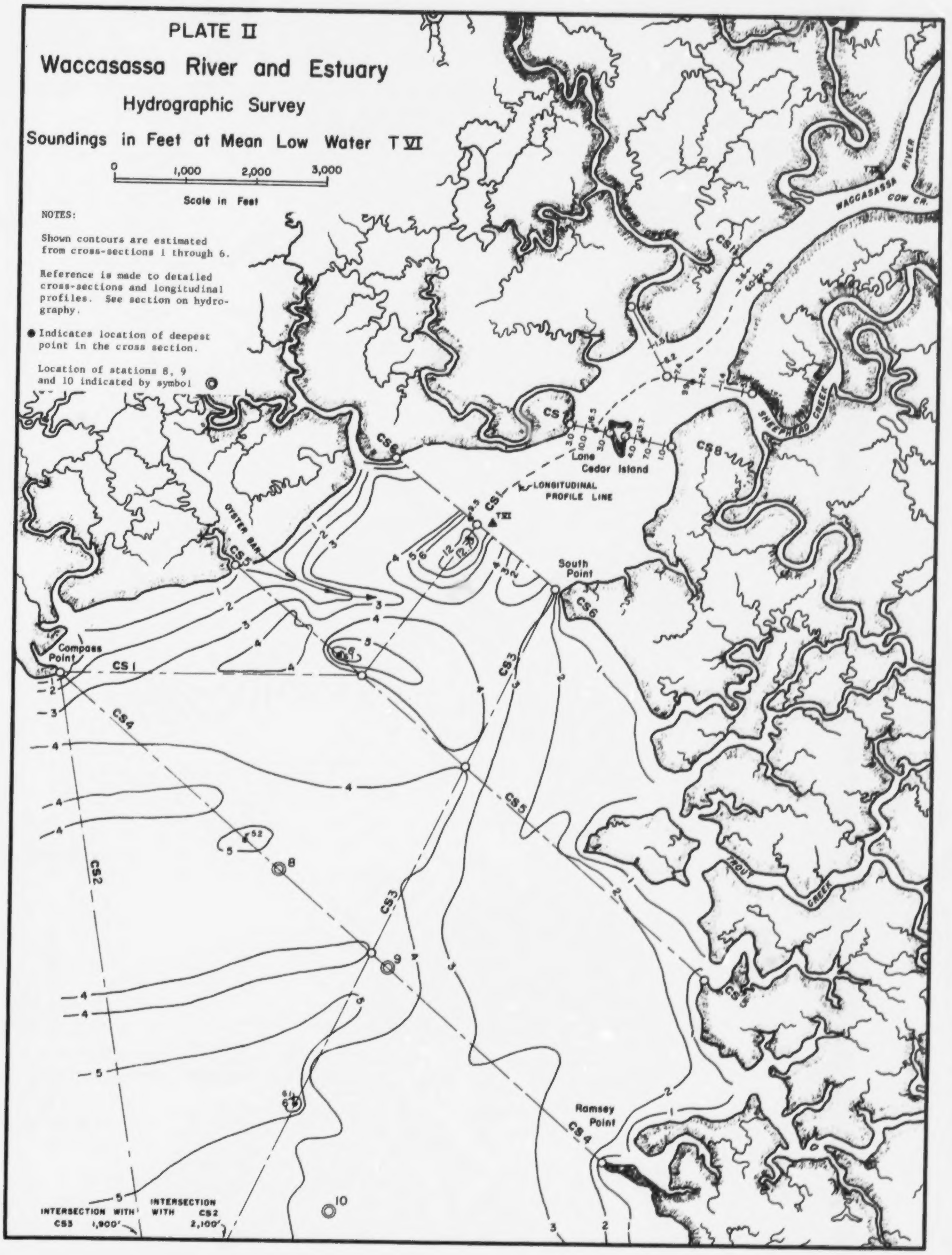


PLATE II

Waccasassa River and Estuary

Hydrographic Survey

Soundings in Feet at Mean Low Water T VI

NOTES:

Shown contours are estimated from cross-sections 1 through 6.

Reference is made to detailed cross-sections and longitudinal profiles. See section on hydrography.

● Indicates location of deepest point in the cross section.

Location of stations 8, 9 and 10 indicated by symbol ◎

0
1,000
2,000
3,000
Scale in Feet
WACCASASSA RIVER
COW CR.
SHEEPHEAD CREEK
TROUT CREEK
OYSTER BAR
Lone Cedar Island
LONGITUDINAL PROFILE LINE
South Point
Compass Point
Ramsey Point
CS1
CS2
CS3
CS4
CS5
CS6
CS7
CS8
CS11
CSL
T VI
8
9
10
INTERSECTION WITH CS3 1,900'
INTERSECTION WITH CS2 2,100'

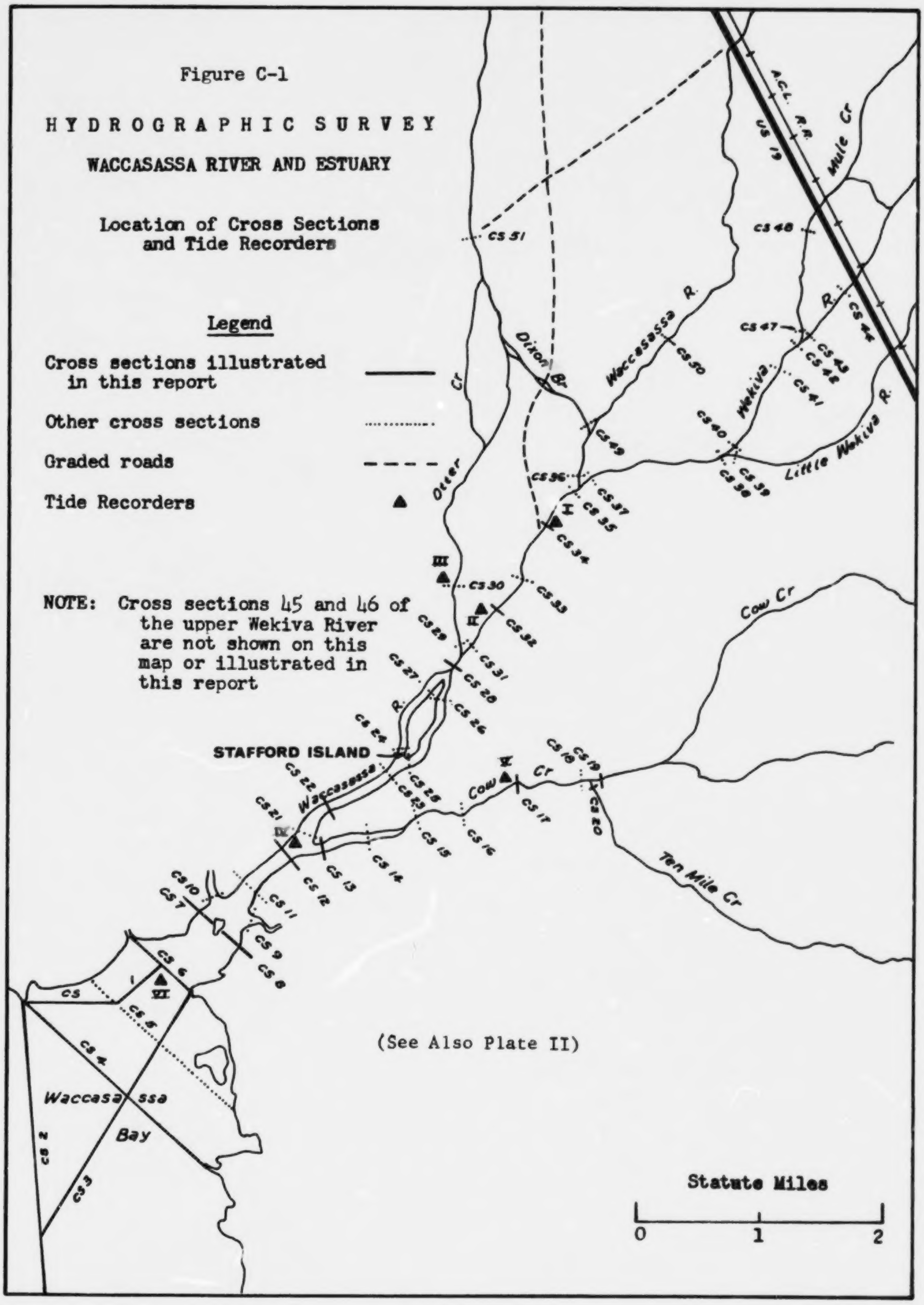


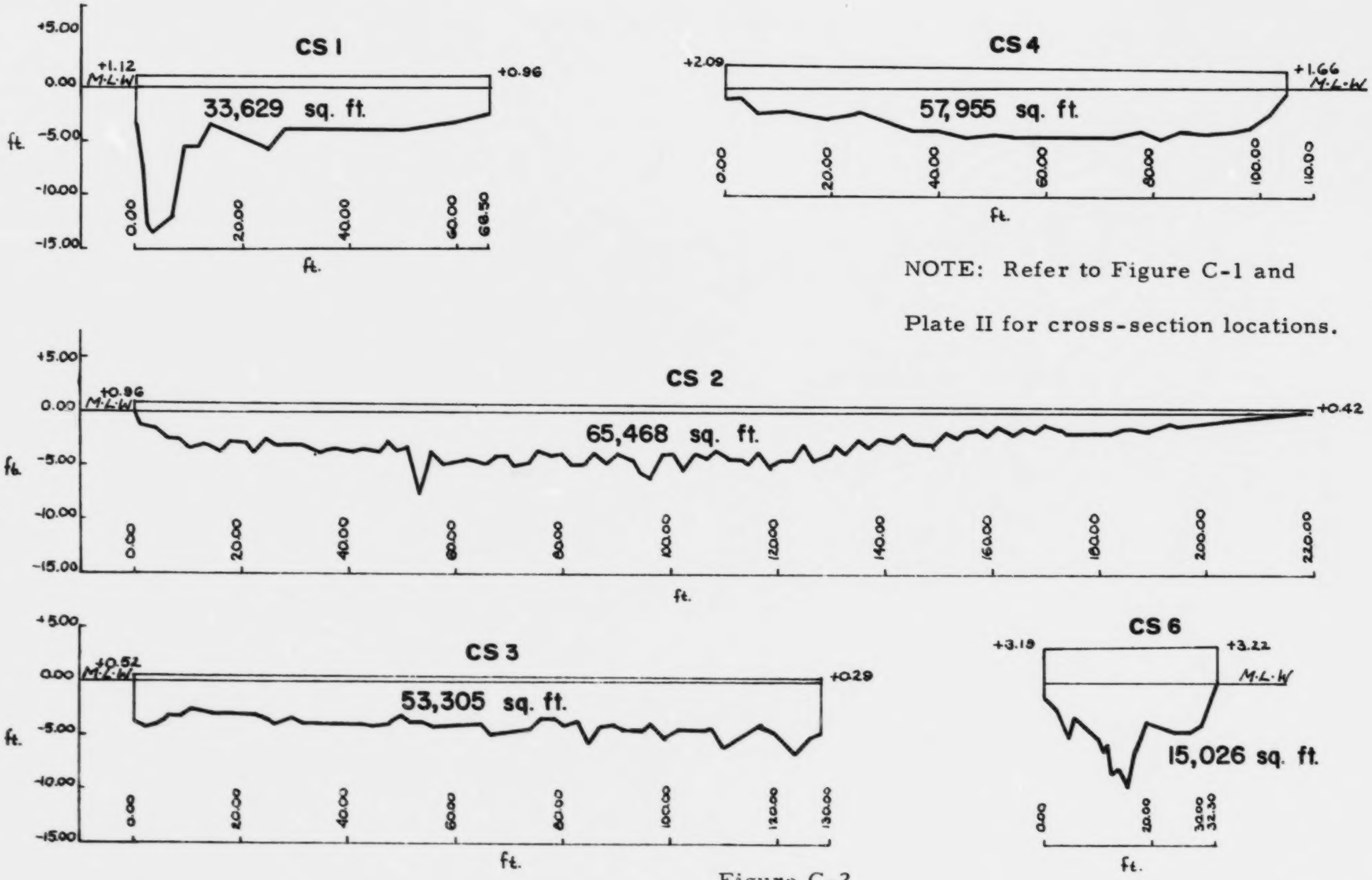
Figure C-1

HYDROGRAPHIC SURVEY

WACCASASSA RIVER AND ESTUARY

Location of Cross Sections and Tide Recorders

Legend
Cross sections illustrated in this report
Other cross sections
Graded roads
Tide Recorders ▲
NOTE: Cross sections 45 and 46 of the upper Wekiva River are not shown on this map or illustrated in this report
ACL R.R.
US 19
Mule Cr
CS 51
CS 48
CS 47
CS 44
CS 43
CS 42
CS 41
CS 40
CS 39
CS 38
Wekiva R.
Little Wekiva R.
Waccasassa R.
CS 50
Dixon Br
Otter Cr
CS 49
CS 36
CS 37
CS 35
I
CS 34
III
CS 30
CS 33
II
CS 32
CS 29
CS 31
CS 27
CS 28
CS 26
R.
CS 24
STAFFORD ISLAND
CS 22
Waccasassa
CS 25
CS 23
Cow Cr
V
CS 18
CS 19
CS 17
CS 20
Cow Cr
Ten Mile Cr
CS 21
IV
CS 15
CS 16
CS 14
CS 13
CS 12
CS 11
CS 10
CS 7
CS 9
CS 8
CS 6
VI
CS
CS 5
CS 4
Waccasassa
Bay
CS 2
CS 3
(See Also Plate II)
Statute Miles
0
1
2

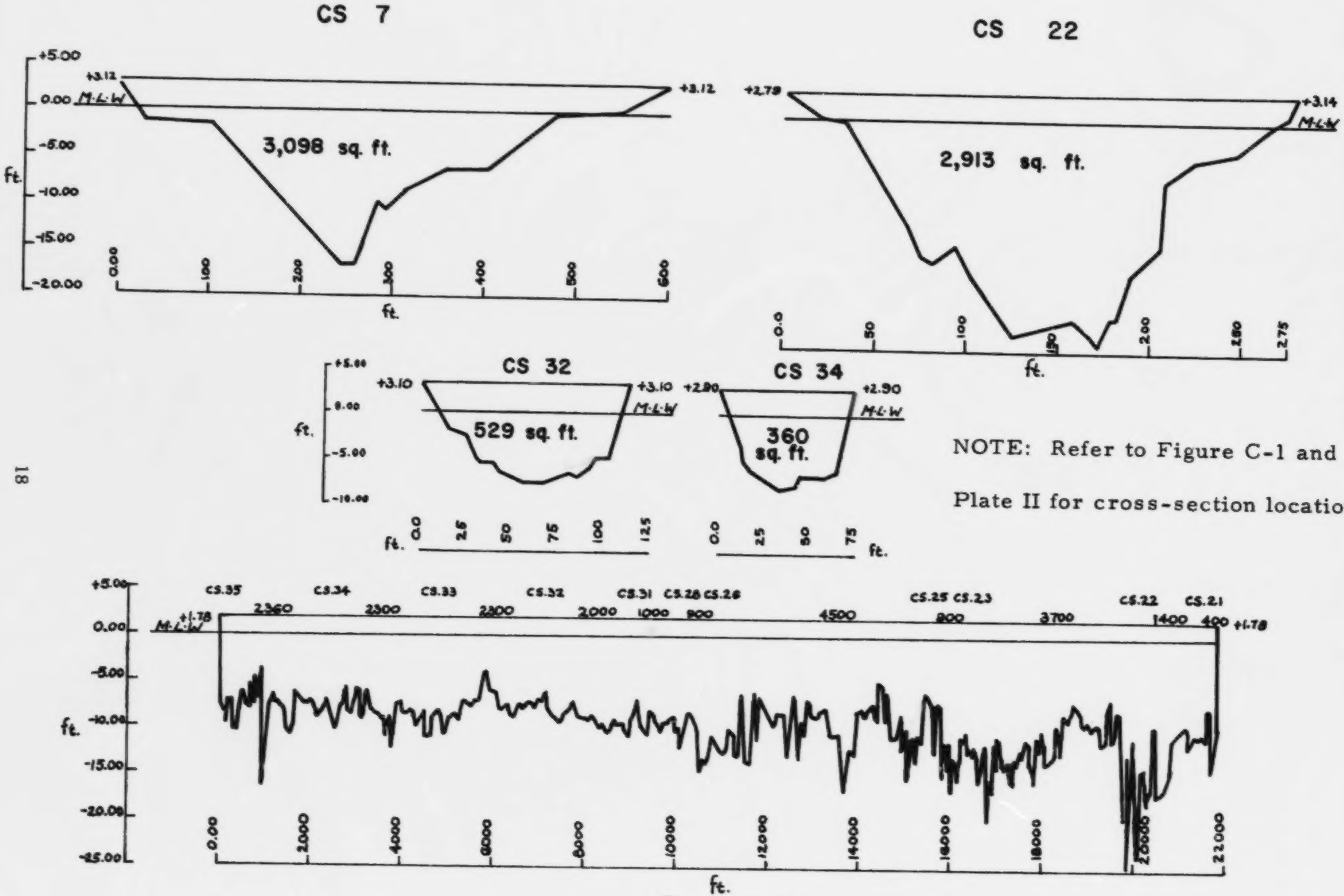


NOTE: Refer to Figure C-1 and Plate II for cross-section locations.

Figure C-2

HYDROGRAPHIC SURVEY

Soundings Referred to MLW Datum at Tide Recorder VI



NOTE: Refer to Figure C-1 and Plate II for cross-section locations.

Figure C-3
HYDROGRAPHIC SURVEY
Soundings Referred to MLW Datum at Tide Recorder VI

long-term averages during the period of the study. These data have been plotted on Figures D-1 and D-2. The actual rainfall quantities shown are regarded as reasonably accurate, particularly as they are used chiefly to indicate the relative wetness or dryness during the period of the study and to interpret various aspects of the limited streamflow data.

From Figure D-1 the seasonal character of the rainfall is evident. Substantial differences in rainfall at the tower stations for the same month occur at times, especially in the summer months, and are due chiefly to local convectional phenomena. This indicates the need for a network of rainfall and stream gaging stations if representative data from such areas are to be obtained.

Rainfall associated with the passage of Hurricane Dora in September 1964 was phenomenally high although the hurricane center was some 80 miles distant. The four-day rainfall (September 10-13) on the drainage area was 17.2 inches, producing severe flood conditions. Hurricane Dora (Figure FD-3) is described later in PART II under FD. HYDROLOGY.

From Figure D-2 it is clear that the greater part of

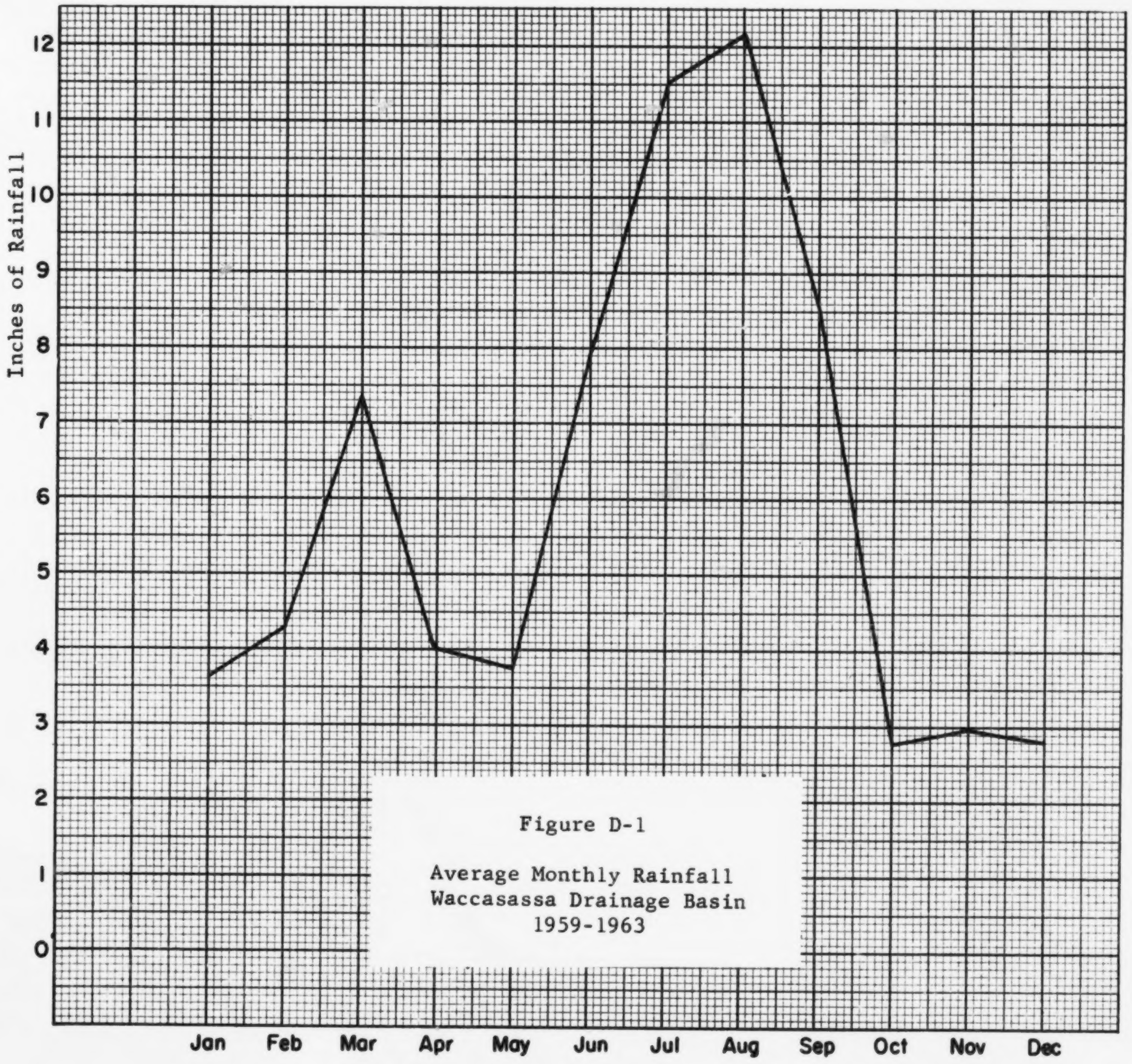


Figure D-1

Average Monthly Rainfall
Waccasassa Drainage Basin
1959-1963

Table D-1

AVERAGE PRECIPITATION ON WACCASASSA DRAINAGE BASIN WITH MONTHLY AND ANNUAL DEPARTURES

A. Approximate Long Term Averages

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
3.62	4.28	7.36	4.01	3.73	7.86	11.53	12.20	8.63	2.77	2.96	2.84	71.79

B. Monthly Precipitation and Departures from Average at Tower Stations During Period of Investigation

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1963	3.84	7.00	4.23	0.63	3.68	6.91	9.65	7.65	6.35	0.59	4.58	3.59	58.68
Dep.	+0.22	+2.72	-3.13	-3.38	-0.05	-0.95	-1.88	-4.55	-2.28	-2.18	+1.62	+0.75	-13.11
1964	13.54	8.85	4.96	6.66	2.21	6.71	23.14	13.86	19.63	3.15	2.41	8.03	113.15
Dep.	+9.92	+4.57	-2.40	+2.65	-1.52	-1.15	+11.61	+1.66	+11.00	+0.38	-0.55	+5.19	+41.36
1965	3.05	8.05	5.16	3.06	1.24								
Dep.	-0.58	+3.77	-2.20	-0.95	-2.49								

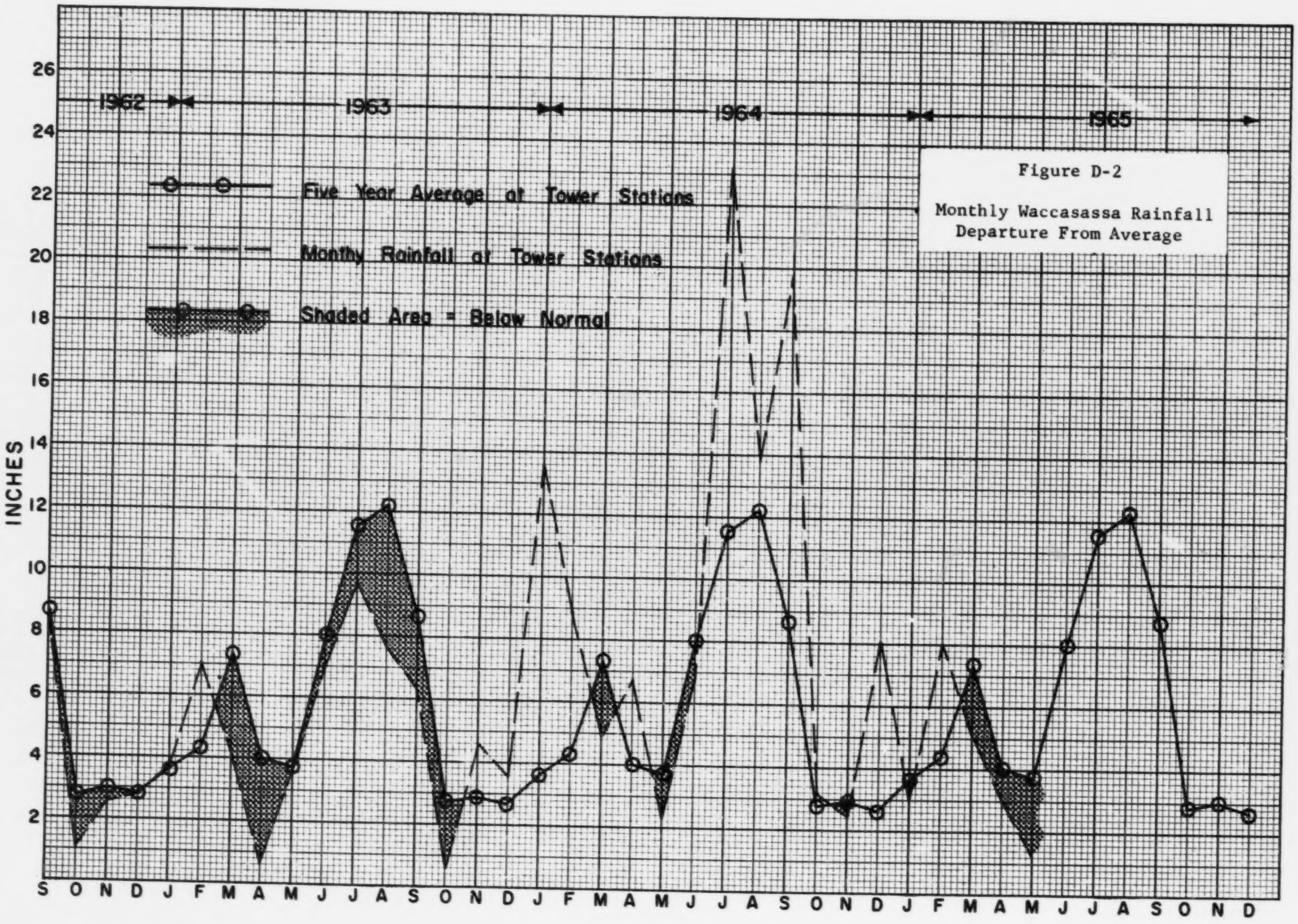
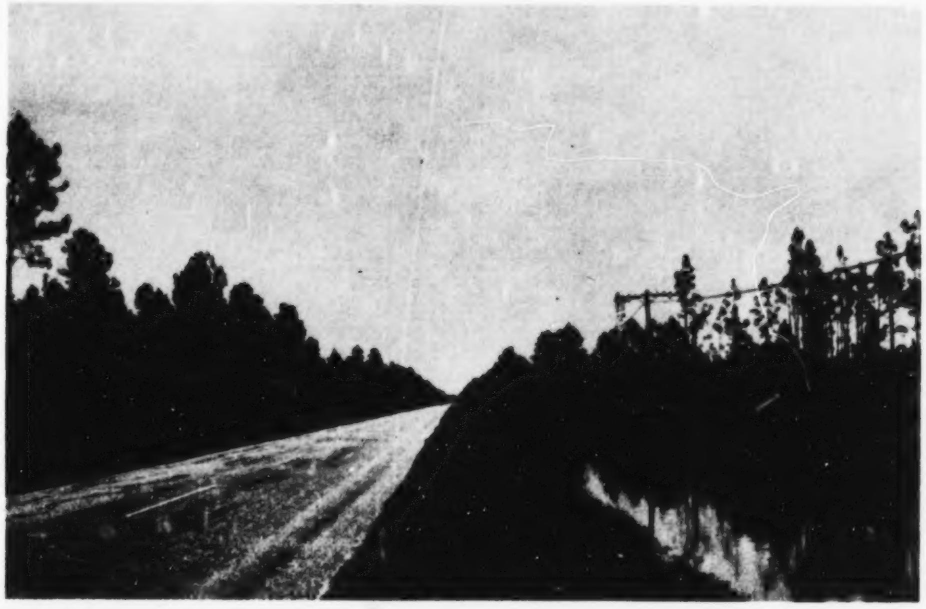


Figure D-2

Monthly Waccasassa Rainfall
Departure From Average

a. The Waccasassa River at State Route 24 on January 28, 1964 looking NE. Runoff is discharging into the stream from roadside ditches on both sides of the highway.



b. State Route 24 NE from the Waccasassa River bridge on January 28, 1964. Runoff in both roadside ditches flowing to the river at a velocity of approximately 0.7 ft/sec.

Figure D-3

Effect of Highway Embankment on Retarding Flood Run-Off

Table D-2

MONTHLY AND ANNUAL STREAMFLOW*
WACCASASSA RIVER AND TEN MILE CREEK

Cubic Feet per Second

Month	Waccasassa River at Station 2 Plus Otter Creek. Dr. Area 400 sq. mi.			Ten Mile Creek at Lebanon Station. Dr. Area 26 sq. mi.		
	Mean	Maximum	Minimum	Mean	Maximum	Minimum
		1963			***1963***	
April	89.3	184	38			
May	105	209	41			
June	103	173	25			
July	117	210	-6			
August	125	189	34			
September	123	314	-14			
October	153	347	55	0.93	7.0	0
November	108	367	-212	0.12	0.4	0
December	151	237	22	0.23	0.6	0.1
Apr.-Dec.	119	367	-212			
		1964			***1964***	
January	423	1420	155	47.7	130	0.7
February	699	1470	241	99.6	292	37
March	411	883	238	67.5	204	18
April	270	1700	72	33.3	306	0.2
May	428	1820	18	40.4	214	0
June	89.3	160	29	0.02	0.4	0
July	1169.3	7090	35	257	2260.5	0.4
August	1093	1750	418	339	878	99
September	2355	11400	-1420	467	3440	48
October	377	757	161	24.4	46	7.6
November	160	268	20	5.2	7.3	3.6
December	485	1740	130	23.0	97	4.0
Year	662	11400†	-1420	117	3440†	0
		1965			***1965***	
January	707	1680	265	13.0	20	8.5
February	964	1630	358	56.7	135	9.9
March	872	1720	436	63.8	201	10
April	256	451	77	2.52	150	0.4
May	111	179	39	0.19	12	0.1

---

*Data from U.S. Geological Survey. (1)

†Peak flow 12200 cfs at Station 2 and 4290 cfs at Ten Mile Creek.

Table D-3

ESTIMATED STREAMFLOW OF WACCASASSA RIVER AT USGS GAGING STATION NEAR GULF HAMMOCK (INCLUDING OTTER CREEK)

Drainage Area – 400 Square Miles

Month 1963	Min. Daily (cfs)	Max. Daily (cfs)	Averages Mo. (cfs)	Sampling Dates	Discharge (cfs)
				4/1	146
				4/8	100
April	38	184	89	4/15	100
				4/22	49
				4/29	137
				5/6	99
May	41	209	105	5/13	98
				5/20	57
				5/27	86
				6/3	145
June	25	173	103	6/11	67
				6/17	99
				6/24	151
				7/1	172
				7/8	55
July	-6	210	117	7/15	106
				7/24	182
				7/29	155
				7/31	172
				8/5	55
August	34	189	125	8/12	183
				8/13	156
				9/3	91
September	-14	314	123	9/9	96
				9/26	164
				10/2	248
				10/7	169
October	55	347	153	10/14	179
				10/21	64
				10/28	55
				10/29	204
				11/6	100
November	-212	367	108	11/8	100
				11/11	113
				11/13	113
				11/19	94
				11/20	113
				11/26	101
December	22	237	151	12/3	237
				12/11	77
1964				1/10	220
				1/13	558
January	155	1420	423	1/16	313
				1/17	398
				1/29	1160
				1/30	1420
				1/31	1200
February	241	1470	699	2/24	326
				3/4	560
March	238	883	411	3/13	310
				3/16	311
				3/17	298
April	72	1700	269	4/8	163
				4/22	120
				5/12	224
				5/14	240
May	18	1820	428	5/25	89
				5/26	96
				5/27	58
July	35	7090	1169	7/7	123
August	418	1750	1093	8/29	574
				9/3	429
September	-1420	11400	2355	9/17	3540
1965				9/24	1000
February	358	1630	964	2/11	739
April	77	451	256	4/12	250
May	39	179	111	5/3	92
				5/4	118

Table D-4

STREAMFLOW AT STATIONS 1 AND 2, TEN MILE CREEK, COW CREEK, AND STATIONS 6 TO 8 ON SAMPLING DATES

Cubic Feet per Second

Date	Stations 1 & 2	Ten Mile Creek	Cow Creek (Estimated)	Stations 6 to 8 (Estimated)
1963				
4/1	121	Flow during this period did not exceed 5 cfs. A uniform flow of 2 cfs has been used.	A uniform flow of 10 cfs has been used during this period.	156
4/8	87			108
4/15	87			108
4/22	43			59
4/29	114			147
5/6	86			109
5/13	85			108
5/20	50			67
5/27	75			96
6/3	121			145
6/11	58			77
6/17	86			109
6/24	126			161
7/1	143			182
7/8	48			65
7/15	92			116
8/5	48			65
8/12	152			193
9/3	79			101
9/26	136			174
10/2	214	5		258
10/7	141	1.5		179
10/14	149	0.1		189
10/21	56	0.1		74
10/28	48	0		65
11/11	94	0		124
11/13	94	0.1		123
11/19	82	0.1		104
11/26	88	0.1		111
12/3	197	0.2		247
1964				
1/10	183	11	33	255
1/29	860	130	390	1290
1/30	1050	115	345	1765
1/31	890	94	282	1482
2/24	260	41	123	449
3/13	248	34	102	413
3/16	249	22	66	377
5/14	200	9.4	28	268
5/25	78	0.2	10	99
5/26	84	0.1	10	106
7/7	103	1.6	10	133
9/17	2100	384.0	1152	4692

Table D-4 (Continued)

Date 1965	Stations 1 & 2	Ten Mile Creek	Cow Creek (Estimated)	Stations 6 to 8 (Estimated)
2/11	590	29	87	826
4/12	208	2.0	6	256
5/3	80	0.4	2	94
5/4	98	0.3	2	120

Drainage Areas in Square Miles:	
Station 1	332
Ten Mile Creek	26
Cow Creek	110
Station 7	550

Discharge Data for Dates not Sampled at Stations 1 and 2

	Discharge from Table D-3			
7/24/63	182	3	9	191
7/29/63	155	2	6	161
7/31/63	172	3	9	181
9/9/63	96	1	3	99
10/29/63	204	0	2	206
11/6/63	100	0.1	2	102
11/8/63	100	0.1	2	102
11/20/63	113	0.1	2	115
1/13/64	558	34	102	660
1/16/64	313	60	180	493
1/17/64	398	71	213	611
3/4/64	560	105	315	475
3/17/64	298	23	69	367
4/8/64	163	13	39	202
4/22/64	120	0.2	2	122
5/12/64	224	13	26	250
5/27/64	58	0.1	2	60
8/29/64	574	141	423	997
9/3/64	429	60	180	609
9/24/64	1000	112	336	1336

the period of routine field work on the Waccasassa (January to October 1963) was characterized by below normal rainfall. In eleven out of the fifteen months in the period October, 1962 - December, 1963 there was below average rainfall, and Table D-1 indicates that the cumulative rainfall deficiency during 1963 was 13.17 inches. This compares with 15.18 inches deficiency at Gainesville from the long-term average and 13.19 inches from the 1959-63 average.

On the other hand, the very dry year of 1963 was followed immediately by the second wettest year of record. Table D-1 indicates a total annual 1964 rainfall of 113.3 inches on the drainage area which is some 41.5 inches (71 percent) above the estimated average. In eight out of the twelve months rainfall was above average, with severe floods due to very heavy rainfall in January, July, and September. In order to obtain samples under other than the abnormally low flow conditions during 1963, some routine and special studies were made at opportune times during 1964 and 1965, thus somewhat delaying work on the Fenholloway.

Streamflow

As described in the preceding section on Geomorphology, the Upper Waccasassa (above its confluence with the Wekiva) and the upper portions of the Wekiva and Otter Creek (Plate I and Figure A-2) have complicated drainage patterns. During less than average flow conditions most of the flow is in fairly well-defined channels and is largely spring fed. During high flow conditions interconnecting channels result in diversions from one sub-basin to another. At times of flood large areas of land are inundated. Figure D-3 shows typical flood conditions with highway ditches flowing toward a bridge over the Upper Waccasassa and land flooded on each side of the highway embankment.

Station 1 (Plate I and Figure A-2) is essentially the head of the Waccasassa Estuary. While the stream at this point and for a short distance above is tidal, the chloride content is minimal, ranging from 15 mg/l at low tide to 500 mg/l at high tide at the surface at very low fresh water flows, and averaging around 12 to 15 mg/l at all stages and depths during floods.

Streamflow to the Estuary. In March, 1963, the U. S. Geological Survey established a stream gaging station on the Lower Waccasassa at Station 2 (Figure A-2). However, streamflow records at this station were not available until after September, 1963, and hence a considerable number of current meter measurements of tributary streamflow were made during the course of the study to assist in estimating streamflow to the estuary. The U. S. Geological Survey has derived a series of factors by which to multiply the discharge recorded at Station 2 to obtain the total flow of the Waccasassa at this point plus the flow from Otter Creek (1).

The Waccasassa is tidal at Station 2, and in addition to the water stage recorder, the station is equipped with a submerged deflection meter, the readings of which are converted by a rating curve to indicate direction and velocity of flow. Daily records of discharge therefore include not only the net fresh water flow past the gaging station, but also the water necessary to satisfy the change in storage occurring in the period between the beginning and end of the day. Hence the reported daily discharge frequently does not represent actual fresh water flow to the estuary under certain conditions of wind and tide. During each ordinary flood tide there is some upstream flow. The station equipment in effect integrates the upstream and the downstream flow, and the net flow is reported as total daily discharge. However, monthly averages as reported in Table D-2 are adequate for the purposes of the present study, as are also most of the daily values for flow on the sampling dates shown in Table D-3. In general, samples were collected on dates when extremes of wind and storm tide did not affect seriously the estimates of streamflow. Comments on negative (upstream) net daily flow and related phenomena are given subsequently under the heading "Wind."

Table D-4 gives the streamflow on sampling dates at Stations 1 and 2. This is the same as recorded for Station 2 without the Otter Creek contribution. Little inflow occurs between the two stations. Flow at Station 4 is substantially the same as that recorded for Station 2 including Otter Creek, as given in Table D-3.

In October, 1963, the U.S. Geological Survey installed a stream gaging station on Ten Mile Creek near Lebanon with a drainage area of 26 square miles. This is a tributary of Cow Creek, which enters the Waccasassa about one-half mile below Station 4. The discharge data for Ten Mile Creek became available in 1964, and the flow on sampling days is given in the third column of Table D-4. Streamflow at the mouth of Cow Creek has been estimated for sampling days in the fourth column of Table D-4 to be three times the recorded flow for the Ten Mile Creek station. Under conditions prevailing on sampling days, no significant fresh water flow enters the estuary between the mouth of Otter Creek and that of Cow Creek. Flow in the Waccasassa below the mouth of Cow Creek is given in the last column of Table D-4, which is the sum of the Waccasassa flows in Table D-3 plus those for Cow Creek in Table D-4.

The availability of the Ten Mile Creek records provided an opportunity to study rainfall-runoff conditions on a 26-square mile drainage area unaffected by tidal influences. A hydrograph of daily streamflow for the water year October, 1963, to September, 1964, was plotted. From a study of this hydrograph and concurrent daily rainfall, the following conclusions emerge:

1. Response of streamflow to rainfall is surprisingly rapid under normal ground water conditions. A rainfall of two or more inches will produce a flood peak within 24 hours, and the stream will return to a base flow within six to eight days. Because these flash floods come and go so rapidly, field observation is likely to underestimate the total contribution of fresh water.
2. The several flood hydrographs are remarkably similar. In superimposing a number of these on a single chart, the characteristics coincide with small variations. Unit hydrograph studies could readily be made if flood control or drainage works were contemplated. The hydrograph shown on Figure FD-5 (Fenholloway) is typical.
3. The effects of prolonged antecedent drought are readily apparent during October-December, 1963, when cumulative rainfall of over seven inches produced an average of only 0.43 cfs* on Ten Mile Creek.
4. The combined effect of prolonged drought plus evapotranspiration is evident in May-July, 1964. With no rainfall from May 15 to June 19, there is no runoff, and then with nearly four inches of rainfall between June 21 and June 30, there is still virtually no runoff. Even with over five inches of rainfall between July 1 and July 6, there was little response of streamflow. Evapotranspiration exceeded rainfall during June.
5. There is nothing approaching a constant relationship between rainfall and runoff. In 1964, the ratio of runoff to rainfall varied from zero in June to 84 per cent in August and 100 per cent in September. For the water year 1963-64, runoff was 52 per cent of rainfall, and for the calendar year 1964 it was 53 per cent.
6. The runoff for Ten Mile Creek cannot be applied to other parts of the Waccasassa Basin or to the basin as

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*cfs = cubic feet per second.

a whole due to (a) the local nature of the rainfall during the summer wet season, and (b) the contribution from artesian springs elsewhere. Thus in June, 1964, rainfall at Lebanon Tower was 3.90 inches, whereas the average for the three other tower stations was 7.65 inches.

A hydrograph of daily streamflow at Station 2 was also plotted. The general characteristics were similar to those for Ten Mile Creek, although the effects of tide and wind were evident. Unit flows (cfsm)* were lower for Station 2 at moderate and high stages but substantially greater for quite low stages due to persistence of flow from springs on the drainage area.

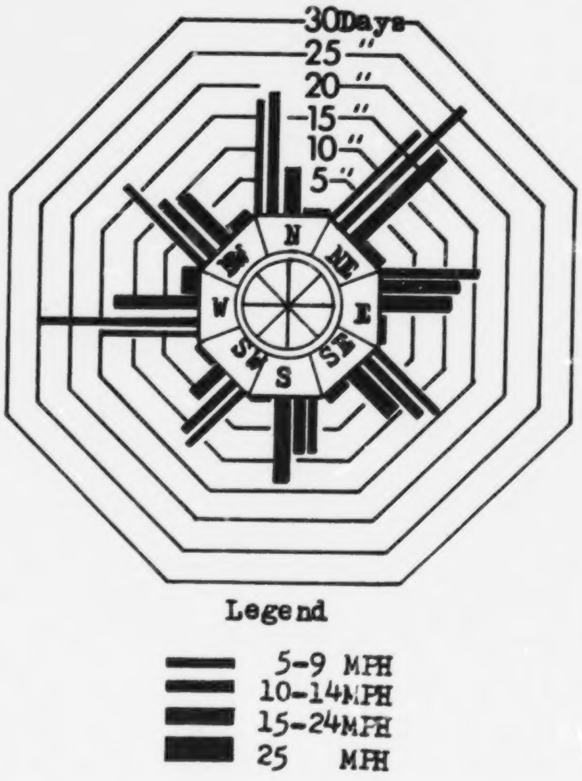
As would be expected from the discussion on rainfall, the year 1964 was one of high runoff, as will be noted from Table D-2. Severe floods occurred in January, May, July, and September. The flood with a peak flow of 12,200 cfs at Station 2 accompanying the effects of Hurricane Dora in September was not only the second highest of record, but was of a magnitude unlikely to be exceeded on the average more than once in over 50 years (2). Due to the low elevation and flat topography of the drainage basin, large areas were inundated in each of the months indicated. The area flooded in September is shown on Plate I. If substantial pollution were to be introduced into the Waccasassa or its tributaries, serious public health hazards might well exist in developed areas subject to flooding unless protective measures were adopted. These would have to include improved drainage to facilitate more rapid runoff of flood waters and probably dikes. Flood control reservoirs are not economically practicable on these flat lands. The generally high flows of 1964 had profound effects upon the quality of the estuary water, especially with respect to salinity. These effects are discussed in other sections of the report.

Wind

The pronounced effect of wind on tidal and streamflow phenomena in the estuary became evident early in the study, and recording wind velocity and direction instruments were installed in June, 1963, at the pier at the town of Cedar Key in the instrument shelter of the U. S. Coast and Geodetic Survey through the courtesy of of the Survey. Data from the wind records were used to plot Figure D-4 and are utilized in the next section in connection with the discussion of wind effect on tide stages. Prevailing winds come from the northeast, as would be expected in an area affected by trade winds.

The availability of records from the wind-measuring installation enabled studies to be made of the correlation between wind direction and velocity with departures of observed tides from predicted tide elevations. From these studies the following explanation of net upstream flow recorded at Station 2 appears reasonable. This phenomenon is mentioned previously in this section under ***Streamflow*** and is indicated in Table D-2. There appear to be two types of events which produce substantial upstream flow sufficient to markedly reduce the recorded fresh water discharge.

Under one set of circumstances, prolonged (one or more days) winds from the north-northeast of 14 to 49 miles per hour preceded the date of net upstream flow. On that date the wind shifted to the south and southeast. Thus, during the first period, the wind forced water out of the estuary, depressing the normal water level in the vicinity of Station 2. Following the wind shift, depleted channel storage was returned to normal or even increased above normal, producing a net upstream flow. Obviously this flow did not represent the correct value of the daily natural fresh water flow. The extent of this phenomenon depends on wind direction, duration, and velocity; astronomical tide, and natural fresh water discharge (3).



WIND DIAGRAM - ONE YEAR PERIOD
WACCASASSA - FENHOLLOWAY AREA
FLORIDA
July 1963 -- June 1964

Figure D-4

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*cfsm = cubic feet per second per square mile.

Table D-5

RAINFALL AND STREAMFLOW ASSOCIATED WITH HURRICANE DORA

September 9-13, 1964

	Waccasassa		Fenholloway	
Date	Rainfall on Drainage Area Inches	Streamflow Station 2 cfs	Rainfall on Drainage Area Inches	Streamflow Station F-101 cfs
September 9	0	288	0	37
10	0.58	-1420	4.62	72
11	9.74	5950	6.82	483
12	5.20	11400	0.85	2710
Sub-Total	15.52		12.29	
September 13	1.64	10700	0	2110
September 9-13 Total	17.16		12.29	
September 14	0	9390	0	1880
15	0	7100	0	1540
16	0.95	4780	0	1230

A somewhat different situation existed in connection with the wind pattern associated with Hurricane Dora (Figure FD-3) which produced the large net upstream flow of 1420 cfs on September 10, 1964. Recorded rainfall and streamflow are shown on Table D-5.

Northerly winds of moderate velocity persisted during September 8 and the first half of September 9, tending to force water out of the estuary. Then about noon on September 9, with the advent of winds blowing into the hurricane center to the north, winds from southerly quadrants began increasing to 40-50 miles per hour, with gusts reaching 56 miles per hour. These created a marked hurricane surge up the estuary, the effect of which is shown on Figure D-5.

This surge produced not only a water level at Station 2 (Tide Station T-II) some four feet above normal high tide on September 10, but essentially eliminated ebb tide effects on that date. It tended to retard the fresh water runoff which was probably not more than 350 cfs. There was a rainfall of only 0.58 inches on September 10. The result was that the upstream surge overcame the downstream flow sufficiently to produce a net upstream flow of 1420 cfs. The retarding effect of the surge continued into September 11, as shown by the relatively low net downstream flow of 5950 cfs, followed by the maximum discharge of 11,400 cfs on September 12. The maximum stage was also recorded on this date and was probably due largely to storm runoff, as the hurricane center had moved into Georgia (Figure FD-3), but intense rainfall continued over the Waccasassa. The very high flows recorded from September 12 to 15 included not only normal flood runoff but also discharge from the vast area of flood water impounded by the surge, as shown on Plate I. The sharp decrease in recorded flow on September 16 indicates a return to normal drainage conditions. It should be noted that the maximum wind velocities shown on Figure D-5 precede the maximum surge elevation on September 11 by about twelve hours. This is because the peak of the surge originating in Waccasassa Bay near Cedar Key, where wind velocities were measured, took about twelve hours to reach the water level recorder at Station 2. This and other aspects of wind effects upon water elevation in the estuary are described under E. TIDAL PHENOMENA.

It is apparent that wind as well as tidal phenomena produce effects which frequently make the recorded daily discharge data not representative of fresh water contributions to the estuary. Similar wind and tide effects occur in the Fenholloway Estuary but stream-measuring stations are located above where such effects are felt, and thus discharge data do represent the fresh water flow.

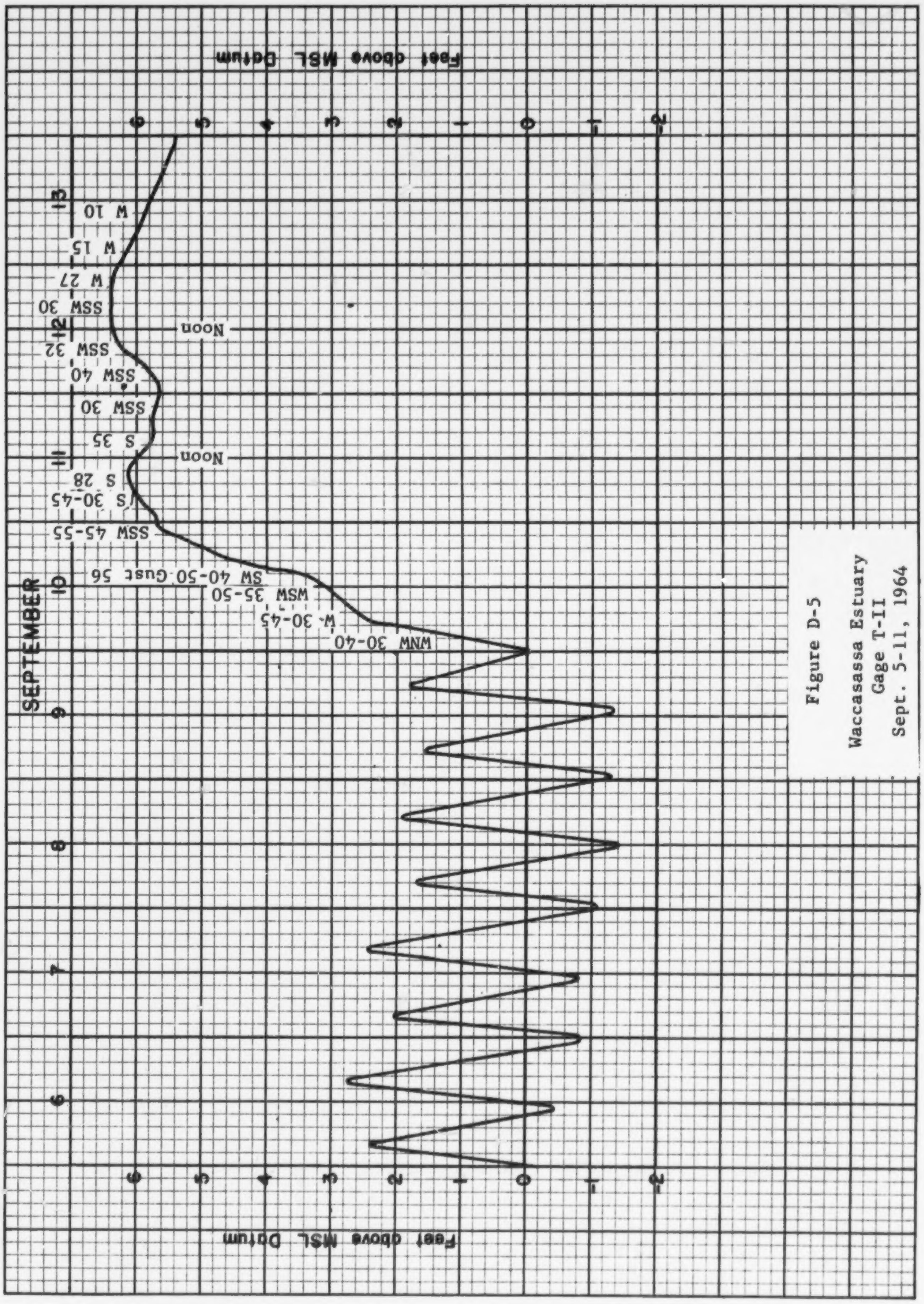

Figure D-5

Waccasassa Estuary
Gage T-II
Sept. 5-11, 1964

E. TIDAL PHENOMENA*

General Characteristics

Tidal phenomena of the Waccasassa River estuary during 1963-64 are of importance in studying its capacity to assimilate pollution. The tides encountered along this section of the coastline of the Gulf of Mexico are of the mixed type (1), (2) which is characterized by two markedly unequal high and low waters each lunar day during most of a lunation. However, for a two- to three-day period occurring twice each lunation, the tidal components interact to give a balanced semidiurnal pattern. Figure E-6 shows these features.

The average variation in sea level during the year in this part of the Gulf of Mexico is shown in the top diagram of Figure E-1. The maximum level is reached in September and the minimum in January, on the basis of records of the U. S. Coast & Geodetic Survey gage at Cedar Key. The periods of lowest Gulf level (December and January) and of highest Gulf level (July to September) coincide respectively with the periods of lowest and highest rainfall (Figure D-1) on adjacent coastal areas. Since higher Gulf levels favor greater saline intrusion into the estuaries, the coincidences tend to cancel out the effects of variations in Gulf level on the quality of estuarine waters.

The lower diagram on Figure E-1 indicates the changes in average annual sea level at Cedar Key and at other Gulf stations. It will be noted that from 1939 to 1961 there was a general rise in sea level (3). Whether or not the decrease from 1961 to 1964 is temporary or denotes a change in the general trend will require additional data. The small change during 1963-64 was not significant with respect to the studies presented in this report.

Gage Data. Primary tidal data were obtained from six recording tide gages of which five were installed for purposes of the study. They are identified as T-I through T-VI and their location is shown on Figures A-2, C-1, and K-1. Gage T-II (at Station 2) is the U.S.G.S. gaging station described in the preceding section and which is equipped to record velocities as well as stage. Wind direction and velocity were recorded by the installation at Cedar Key.

The U. S. Coast and Geodetic Survey very kindly made computations and furnished information indicating that zero on Gage T-VI was -1.51 feet Mean Sea Level Datum (1929). The corresponding MSL elevations of zero on the other gages in the estuary were then readily determined.

Hydraulic Characteristics of the Estuary

Hydraulic Gradients. Average longitudinal profiles of the estuary water at different stages are shown on Figure E-2. The mean slope of the water surface is very flat. It is naturally steepest in time of flood, as shown on the profile for January 24-31, 1964. It is interesting to note that this slope, even though steeper, lies below the mean slope for 1963, since the Gulf level is at a low elevation in January. The slopes on the Fenholloway are substantially greater as described under FE. TIDAL PHENOMENA. Mean and diurnal tide ranges can be determined from Figure E-2. They average about 2.57 and 3.21 feet respectively.

Velocity of Tidal Wave. The mean time of travel of the tidal wave up the estuary is appreciably longer than the time derived from the formula $v=\sqrt{gd}$ for open waters. Assuming an average depth of six feet, the formula would indicate a travel time from T-VI to T-I of about thirty-five minutes. Actually it is approximately one hour, due to substantial frictional resistance from the irregular rocky bottom, the meandering course, and the heavy vegetation along the banks. Diagrams were prepared so that the U. S. Coast and Geodetic Survey tide tables based on St. Marks River Entrance could be used to predict times of stages at sampling stations on the Waccasassa.

Tidal Prism. Volumes of the tidal prism for various stretches of the estuary were computed from cross sections (Figures C-2 and C-3) and instantaneous water surface profiles from recording gage data. The tidal prism between the outer and inner range lines (Cross Sections 4 and 6 on Plate II and Figure C-1) is about 130×10^6 cubic feet, and the tidal prism between the inner range line (Cross Section 6) and the head of the estuary at Station 1 is about 39×10^6 cubic feet.

Currents. Tidal currents were measured at a number of locations along the estuary during the period of the study to determine the circulation pattern. These observations were generally made in the center of the stream at one foot below the surface and then at three-foot intervals from the surface. They do not, of course, represent the average velocities in the estuary cross section.

Figure E-3 shows the variations of velocity with tide stage at six depths at Tide Station IV, near the center of the estuary. A notable feature is the very rapid change from flood to ebb current following high tide. This is characteristic of similar observations at other stations in the estuary above Cow Creek during the low fresh water flows of 1963. This can be explained, at least in part, from Figure E-2, where it will be noted that the low tide slopes are greater than those of high tide. The tide begins to fall at Tide Station VI about an hour before it begins to fall at Tide Station I, producing

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*Some of the material in this section has been published in "Tidal Characteristics of Two Estuaries in Florida," by William B. Stelzenmuller. Proceedings Paper 4431, *Journal of Waterways and Harbors Division,* American Society of Civil Engineers, August 1965.

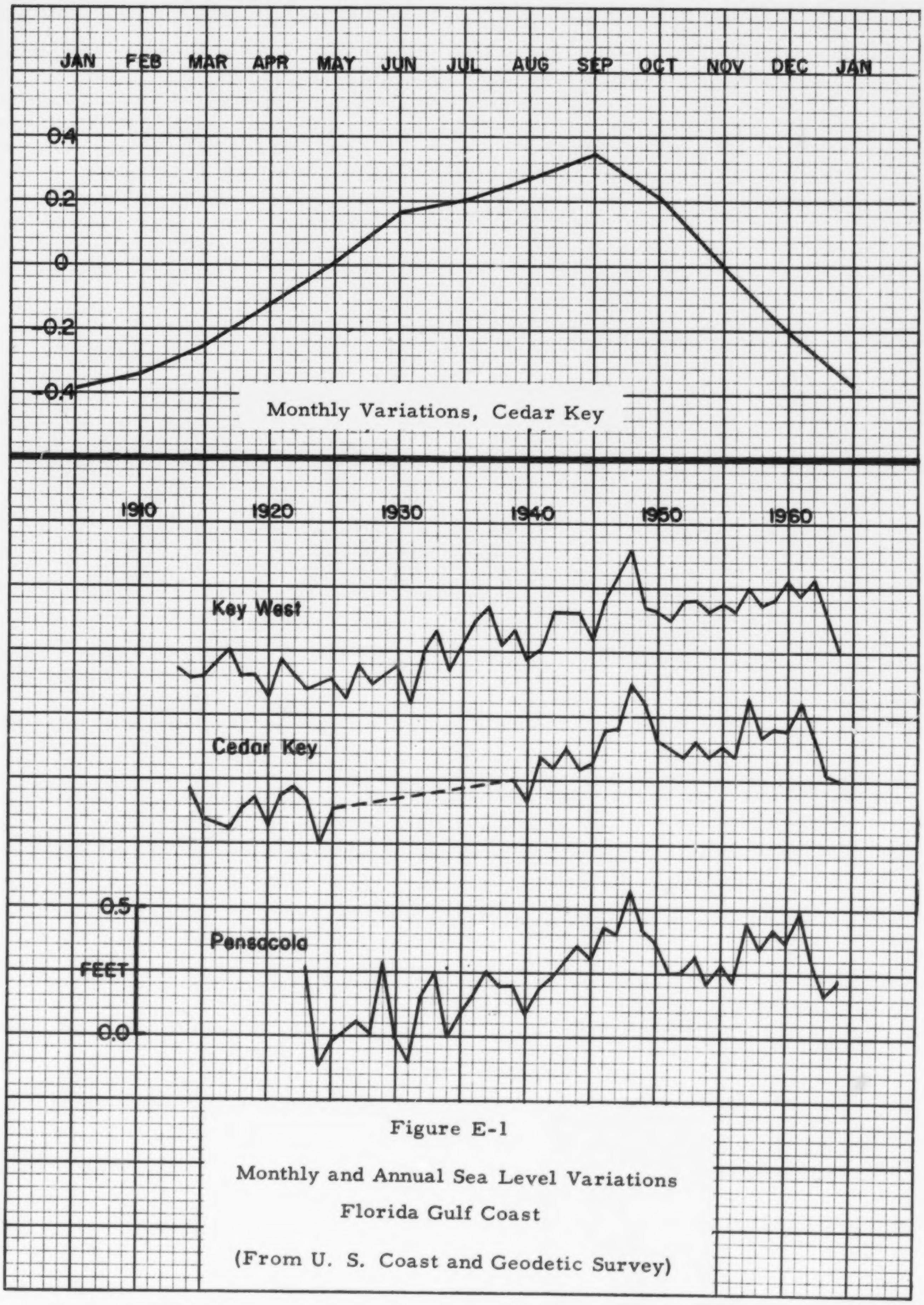

Figure E-1

Monthly and Annual Sea Level Variations
Florida Gulf Coast

(From U. S. Coast and Geodetic Survey)

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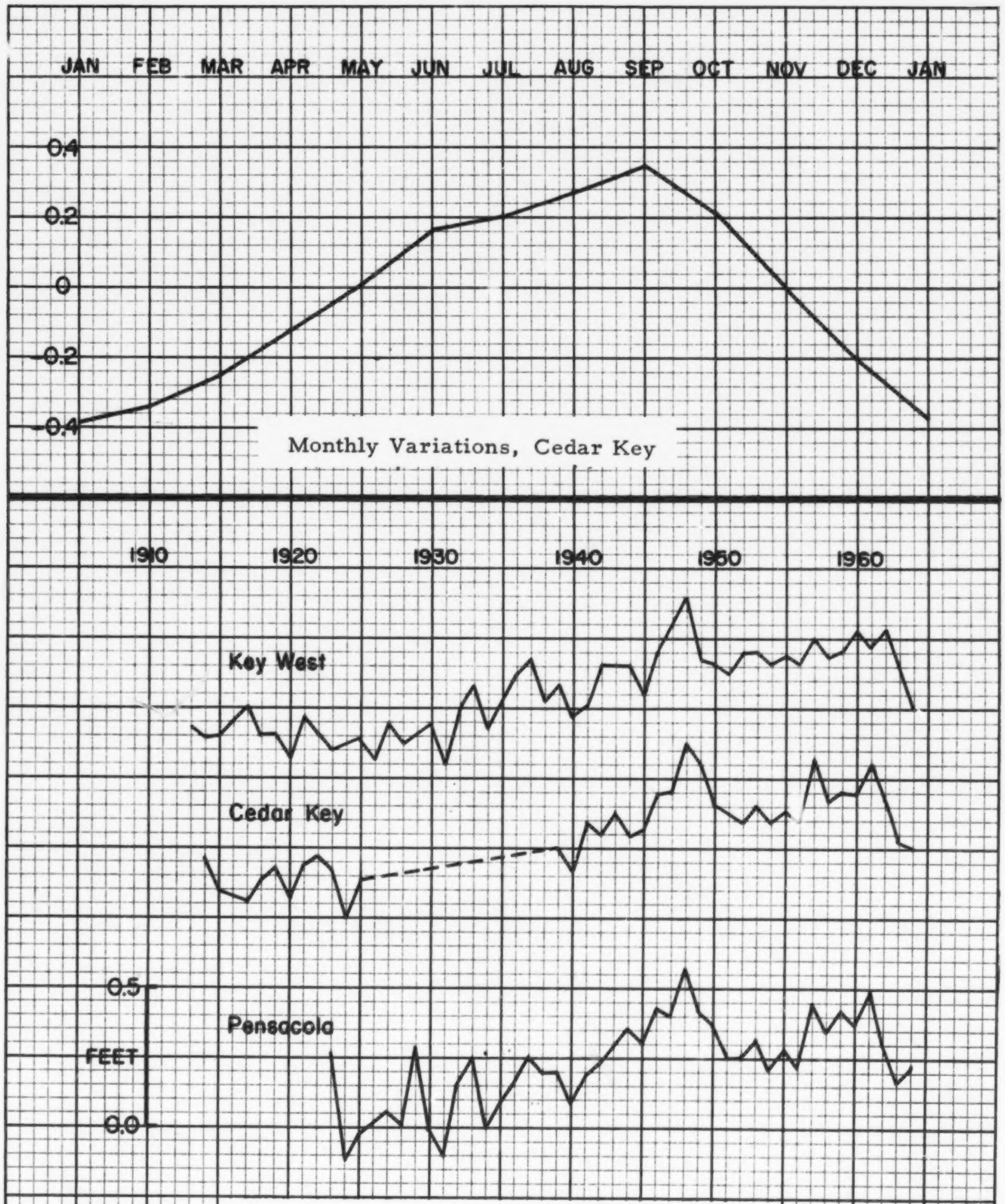


Figure E-1

Monthly and Annual Sea Level Variations
Florida Gulf Coast

(From U. S. Coast and Geodetic Survey)

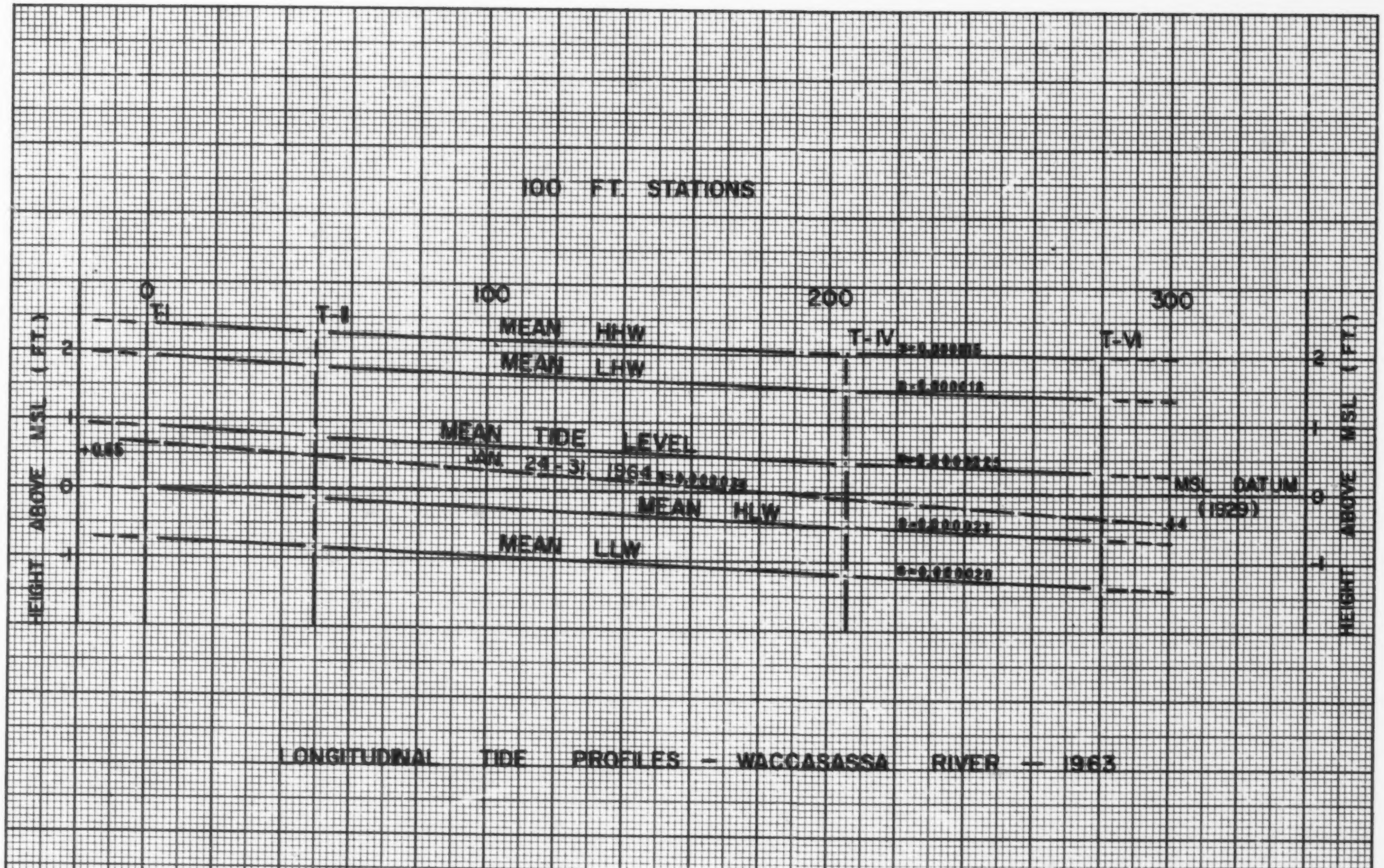


Figure E-2

Longitudinal Profiles of Mean Tidal Heights, 1963 - Waccasassa Estuary

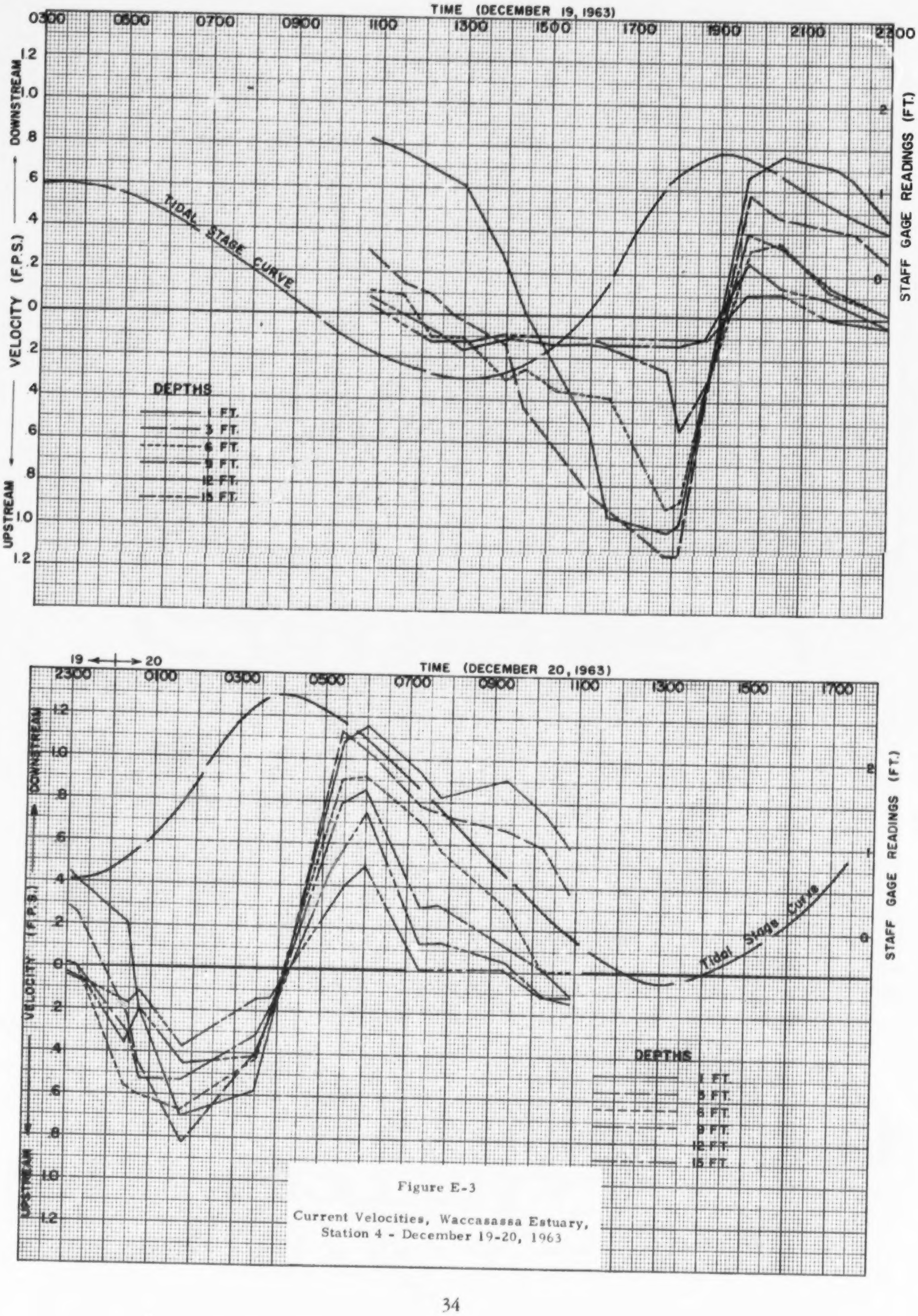


Figure E-3

Current Velocities, Waccasassa Estuary, Station 4 - December 19-20, 1963 a maximum downstream gradient shortly after high tide at upstream stations. This phenomenon is obliterated under certain wind conditions and during fresh water floods.

Vertical velocity profiles are shown in Figure E-4. There is no indication of any consistent variation of velocity with depth. Hence mean velocity in a section cannot be approximated by the velocity at some standard depth.

To obtain data regarding mean velocities of tidal currents at the tide gages along the estuary, a composite tidal curve at each gage was prepared during a four-day period when tidal patterns were similar. Mean velocities were computed by the cubature process of Pillsbury (4). Fresh water discharge was about 150 cfs. The results of these computations are shown on Figure E-5.

The velocity hydrographs indicate that mean velocities for this low flow condition in the river reach a maximum for a given tidal cycle in the vicinity of T-II. Velocities in the downstream direction are definitely higher at T-I and T-II than are upstream velocities, reflecting the important influence of fresh water flow, even as low as 150 cfs.

Because of the availability of the deflection meter at T-II, it was possible to compare the results of the cubature computations with observed deflections, which could be transformed to mean velocities at the section by a rating curve. The velocities obtained at T-II by both methods are given on Figure E-5. It appears that there is rather good agreement on downstream velocities, but the upstream velocities are low for the cubature on the first flood tide and higher than the observed deflection meter velocities on the second flood tide. It seems probable that the cubature method is not quite sensitive enough to show the exact shape of the actual velocity hydrograph, but it is believed that these hydrographs provide information sufficiently accurate for the purposes of this report. Data which were developed in this section on Tidal Phenomena were utilized in the diffusion studies under K. DIFFUSION AND POLLUTION ASSIMILATION and to some extent in other sections.

The Waccasassa River is a small and sluggish stream when compared with larger estuaries for which tidal studies have been made.

Wind Effects

Wind stresses acting upon the surfaces of the shallow Gulf of Mexico and embayments off Florida's west coast (such as Waccasassa Bay) at times other than during storms and hurricanes can bring about a water-level change as great as that resulting from the periodic tide-producing forces. These nonperiodic or intermittent periodic wind effects must be superimposed on the tide-level predictions published by the U. S. Coast and Geodetic Survey if such predictions are to be meaningful at all times (5).

Figure E-6 shows the effect of winds of the periodic tides at T-VI. North-northeast winds of 20 to 30 miles per hour over a period of approximately 18 hours depressed the predicted low tide of 0.4 foot due at 1230 hours on September 23, 1963, to -1.70 feet, or a total depression of 2.1 feet, and almost completely negated the effects of the following high tide. On September 29 the opposite meteorological effects are clearly indicated as the result of southeast and south winds at 15 to 25 miles per hour. When one considers the approximately four-foot average (MLW) depth of Waccasassa Bay, the importance of the calculation of the meteorological tides in this and comparable areas is evident.

Figure E-7 shows the effect of the high velocity winds at the same station during the passage of Hurricane Dora in September, 1964, the path of which is plotted on Figure FD-3. Figure D-5 shows the corresponding trace of tidal stages at Gage T-II, four miles upstream. A discussion of the wind effects upon streamflow at this station is presented under D. HYDROLOGY.

Circulation in the Bay

A considerable number of current observations were made in the Waccasassa Bay during the period of study to determine the tidal circulation pattern. In these very shallow waters wind has a decided effect on current direction and mean velocity. Current observations corrected for the effects of wind indicate a normal circulation pattern as shown in Figure E-8. It will be noted that ebb currents trace a more southerly course than do the flood currents. The circulation within the bay is generally counterclockwise as has also been indicated by other studies (6), and it is to be expected that there will be a translation of the fresh water flow from the river and nearby creeks in a southerly direction along the coast, i.e., generally toward the mouth of the Withlacoochee River.

F. MICROBIOLOGY

Introduction

There are very few studies of estuaries in which biological connotations and finds are set forth and related to the chemistry and hydrology of the area. For this reason alone a detailed biologic study of the Waccasassa River and Bay should be of interest. But there are other reasons. This watershed is an area which is very sparsely inhabited and has little arable land; hence it should contain very little leached-in fertilizer. Finally, there are no industrial drainages. The only man-made changes

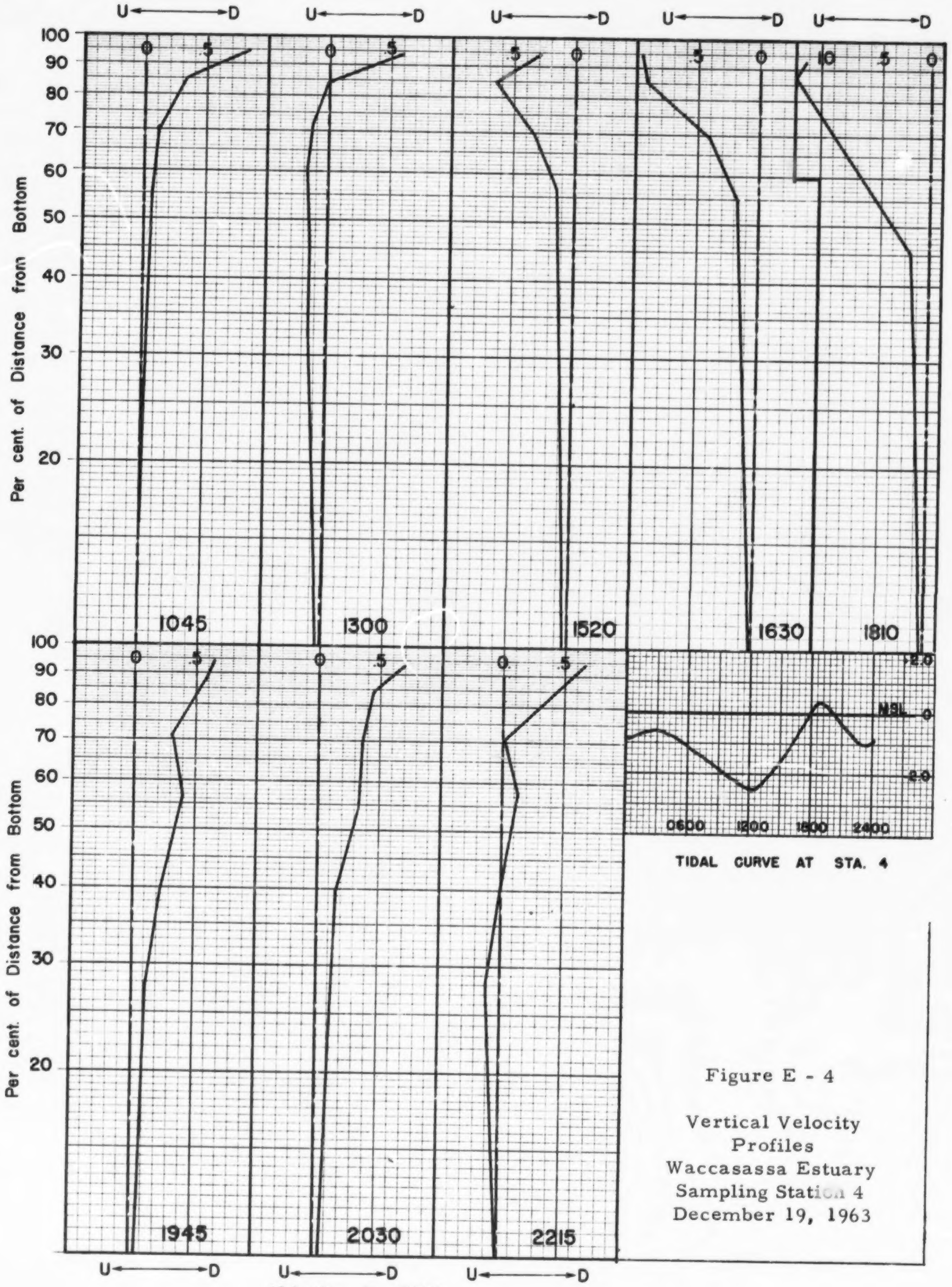


Figure E - 4

Vertical Velocity
Profiles
Waccasassa Estuary
Sampling Station 4
December 19, 1963

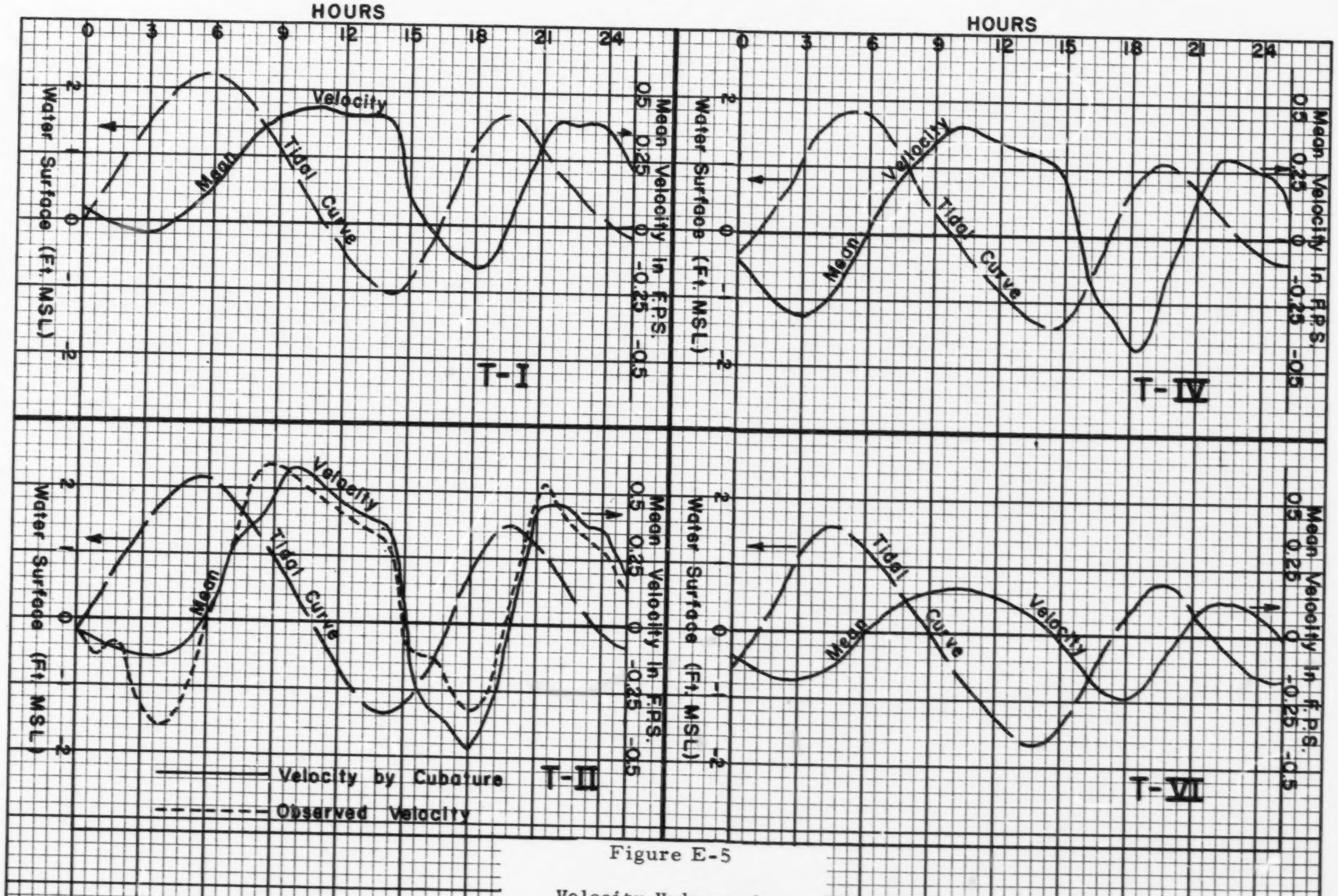


Figure E-5

Velocity Hydrographs
Waccasassa Estuary
July 31-August 3, 1963

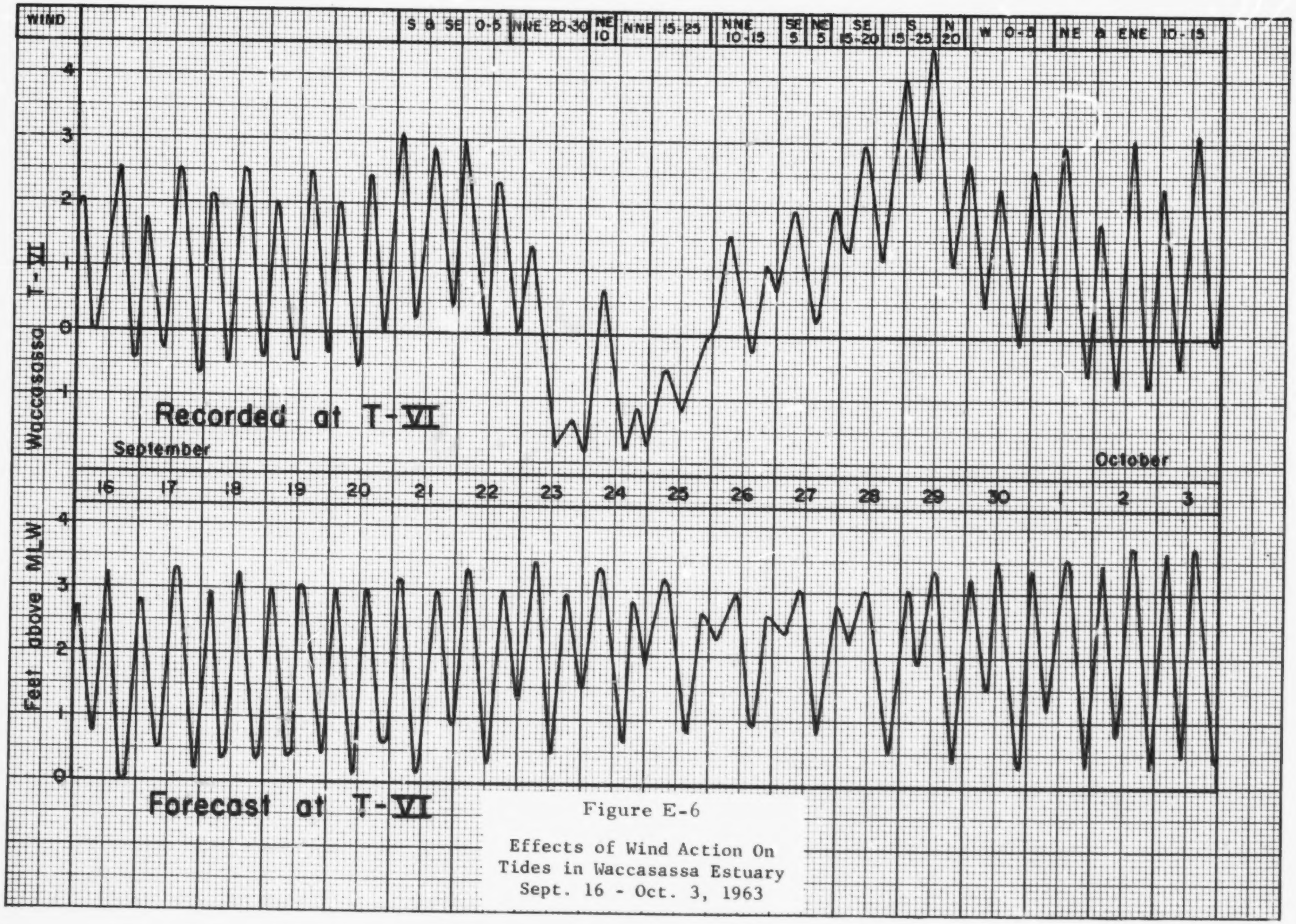


Figure E-6

Effects of Wind Action On
Tides in Waccasassa Estuary
Sept. 16 - Oct. 3, 1963

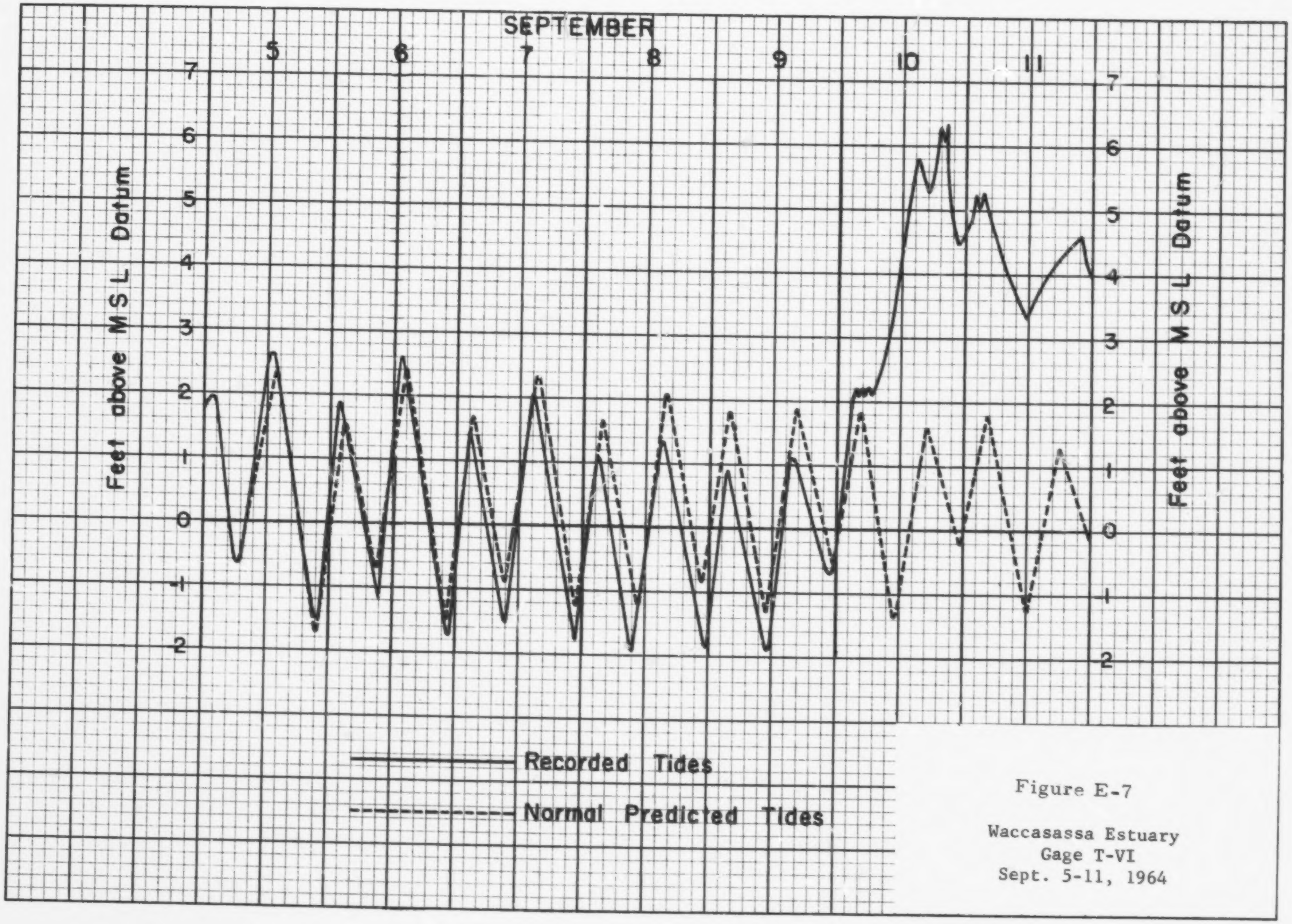


Figure E-7

Waccasassa Estuary
Gage T-VI
Sept. 5-11, 1964

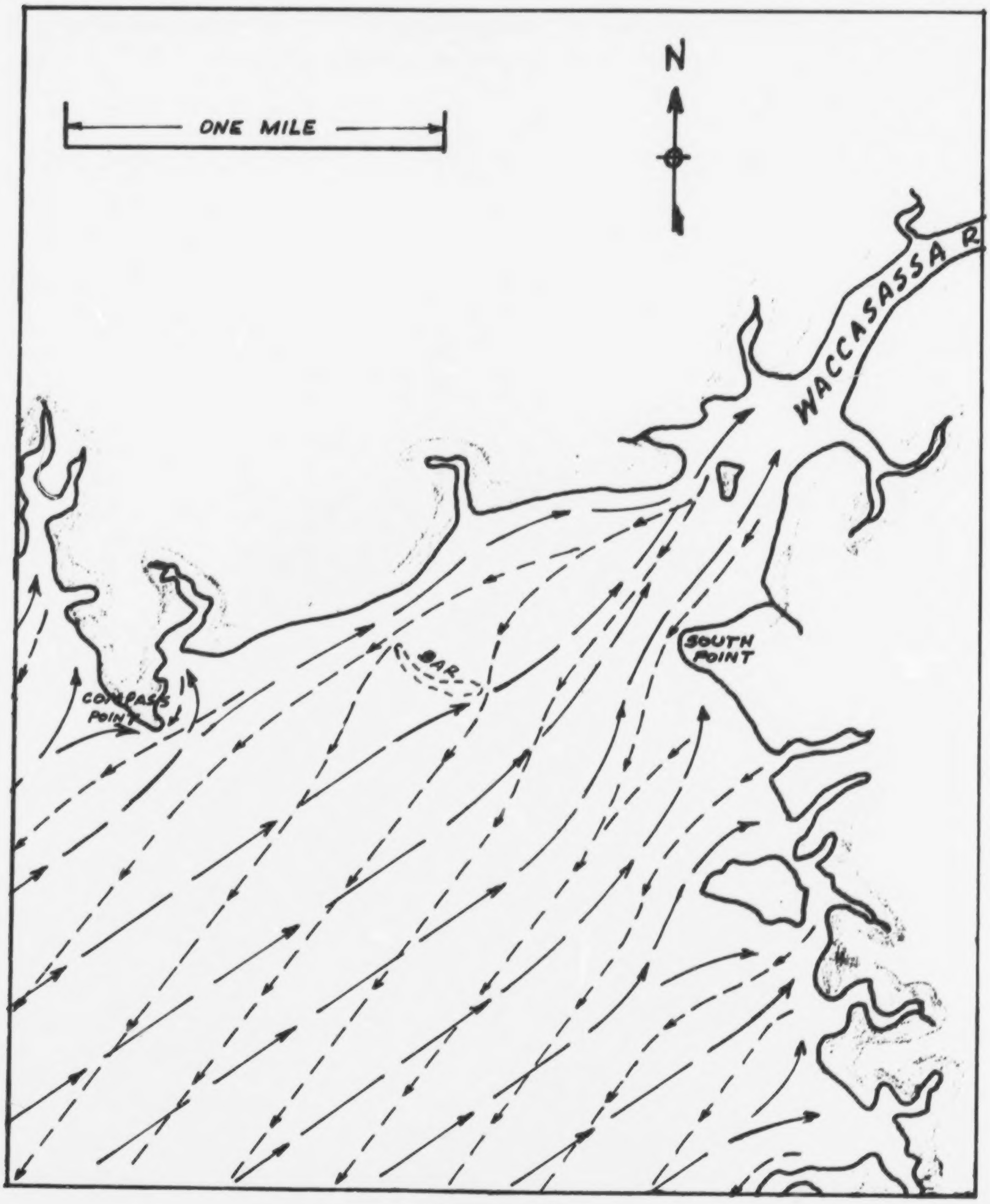

ONE MILE
N
WACCASASSA R
SOUTH POINT
BAR
COMPASS POINT

Figure E-8

Normal Pattern
of
Tidal Currents
Waccasassa Estuary

of consequence were due to the long-past lumbering industry. Once the area was cut over, reseeding soon replaced the lost trees. The result is an area in which man's influence is low, a rare occurrence in this day.

Fertilizing materials, especially nitrates, leach rapidly into the soil of the uplands, and cursory examinations of the plankton algae of the river where it crosses SR 24 and of Johnsons pond (see Plate I) indicate low plankton content. This reflects the low nutrient level. Surface drainage waters are generally brown in color. The large springs produce clear, colorless water and originate from the limestone aquifers of the region.

Presuming that nitrogen and phosphorus are probably the limiting factors in microorganism production in the Waccasassa drainage, and hence for total organism production, it is not expected that the watershed would produce an enriched water. This presumption is verified in plankton examinations and is discussed later.

The salt marshes are also vegetation covered, principally with *Spartina* and *Juncus*. Trees are usually cabbage palmettos and bayberry, few in number. They are penetrated by tidal creeks such as Cow, Ten Mile, etc. In these creeks there are frequently good growths of one species of attached brown alga *(Sargassum)* which impedes current, is a good oxygenator, and is a site for heavy microorganism growths. Much of the salt marsh area is intermittently flooded to a depth of one or two inches or more, but the flooding is largely dependent on wind-driven tides and heavy rainfall. Nevertheless, the marshes are vast areas where aerobic decomposition of organic matter occurs. The adjacent marshes do not contribute large numbers of microorganisms to the estuary, although large numbers and long species lists may be recovered from them.

Stations and Examinations

Plankton samples were collected from the project stations (Figure A-2) at bimonthly intervals. One-liter bottles were filled at the surface or one foot below. These were iced, protected from sunlight, and brought to the laboratory. There, 100 ml aliquots were centrifuged in a clinical centrifuge carrying 50 ml conical-ended tubes; the supernatant decanted with a pipette; the catch made up into drops so that one drop normally equaled one ml of raw water and also equaled sixteen paths across the

Table F-1*

ORGANISMS ENCOUNTERED IN THE WACCASASSA SYSTEM AND ESTUARY

Organism Group	No. Species	No. Occurrences
Sulfur and Iron Bacteria	7	37
Blue-green Algae	13	33
Green Algae, sensu strictu	9	245
Green Flagellates, Volvocales	20	228
Green Flagellates, Euglenophyceae	14	108
Colorless Flagellates	36	194
Green and Colorless Flagellates, Chloromonadida	6	54
Olive Green and Colorless Flagellates, Cryptomonadida	10	533
Yellow-Green Flagellates, Chrysophyceae	21	203
Colorless Flagellates, Ebridiens	2	9
Yellow Flagellates, Coccolithophora	2	3
Dinoflagellates	39	354
Diatoms	71	1907
Rhizopods, Amoebas, etc.	33	78
Colorless Flagellates, Zooflagellata	51	877
Ciliates, Ciliata	84	595
TOTALS	418	5458

*This table is a condensation of a much more detailed table listing all of the species. A copy of this latter table is available on request. Some references to Table F-1 in the text relate to the unabridged table.

microscope stage at a magnification of 100 diameters, or 64 paths at 400 diameters. This enabled identification to genus and species of about 95 per cent of the algae, protozoa, and sulfur bacteria, and was quantitative as well. No counts were made of the rotifers, nematode worms or gastrotrichs which were occasionally found. Only a few plankton tows were made, and benthic protista were investigated only qualitatively.

The Organisms

The Fresh Water Stations. Sampling began in the fresh water of the river. Table F-1 is a list of the microbiota which were noted in the survey including both fresh and saline water areas. This table includes some additional organisms recorded from slides suspended in the river and from bottom collections and does not represent only the suspended forms. The number of species is large, but considering the habitats represented, not too many per ml. The numbers of individuals is not impressive. The fresh water species are those which might be expected in an oligotrophic (low nutrient level) swamp drainage. Considering the area drained as to size and age of water, the list is very small indeed.

The numbers of photosynthetic suspended organisms are so low as to exert either no effect or a very small effect on oxygen levels in the estuary. As shown in Figure I-1 the median low tide DO of 11 mg/1 at Station 102 indicates supersaturation. This is presumably due to the abundance of attached emergent and submerged vegetation, as well as turbulent, shallow water. The dissolved oxygen drops rapidly between Station 102 and Station 1 but is rarely less than 75 per cent of saturation below Station 1.

A study of the Wekiva for about three miles above Station 102 showed the existence of large amounts of *Chara, Valisneria,* and *Naias* as submerged vegetation. The submerged vegetation is quite active in adding oxygen and illustrates normal processes common to these coastal streams. Fish of several species were abundant. Similar conditions were observed on the Upper Waccasassa.

Microorganisms are not abundant as suspended forms in either the Wekiva or Waccasassa rivers above Station 1. Numbers are so few that quantitative considerations have no meaning. The recorded species are regarded as ubiquitous and significant only if they occur in large numbers. On the whole, the microscopic fresh water protozoa and algae of the upper river may be dismissed as of negligible importance as to work, indicator significance, or seeding of the lower areas.

The Mixing Area. Beginning at Station 1 and extending past Station 6, the biological indications are that this is an area where the greatest mixing of fresh and salt water occurs.

Organisms living in a mixing area must be quite tolerant of physical and chemical changes. These characteristics may fluctuate widely. Many fish tolerate these changes. Thus large mouth bass which are normally fresh water fish are often taken far downstream in the Waccasassa. Mullet and other fish are taken well upstream in low salinity areas. These, however, can migrate at will long distances in a few hours. The vegetation is another matter. *Chara, Valisneria,* and *Naias* virtually do not occur at or below Station 1. *Water hyacinths (Eichornia)* die on entering this area, and red and brown algae brought into the area by tidal action are also found only in a moribund condition.

Plankton algae and protozoa have been conspicuously low in the estuary. The most numerous organisms, percentage-wise, have been cryptomonads, Chrysophyceae, and diatoms. Most of the latter have been benthic types, brought into suspension by the currents prevalent in this section. There have been some blooms (accepting 500/ml or more as defining "bloom") but they have been few in number. Tables F-2 to F-5 inclusive show the percentage of organisms in each of fourteen groups from samplings made near the head of the estuary (Station 2) proceeding downstream to the mouth. It will be noted that the great bulk of the population in these samplings is made up of Volvocales, Chrysophyceae, Cryptophyceae, diatoms, and zooflagellates. Figure F-1 shows the total numbers of organisms per sample at Stations 1 and 2, and only in April did the number per ml exceed 400. These figures may be somewhat misleading since they do not take size into account.

No rigid separation of planktonic and benthic organisms is made in this report. The large species list of supposedly benthic diatoms is due to current action sweeping bottom forms into suspension.

The qualitative aspect of the suspended organisms is unusual in one respect – a much smaller list was found than was anticipated in either the upper reaches or the mixing area. The upper reaches were expected to yield a large number of species, comparable perhaps to the list for the Santa Fe River (1), but no large quantities. Either the headwaters or marshy margins do not produce a large variety, or they are not swept into suspension. The latter is probably the case.

The mixing area is designated as a short stretch around Stations 1 to 6. Here there are few shallow marginal areas in which a microbiota might establish itself. The currents are appreciable, and while detention time in the area may be drawn out due to tidal reversal, there is certainly no long generative time. Therefore, the organisms are adventitious and either originate in the headwater regions but survive long enough to be enumerated in sampling, or they are swept in from the salt water stretches. In this connection it should be remembered

Table F-2

PER CENT OCCURRENCE OF EACH GROUP IN EACH SAMPLE AT STATION 2

	January		February		March	April			May		June	July		Sept.
Beggiatoales	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Myxophyceae	0	0	0	0	0	2	0	0	0	0	1	0	0	0
Volvocales	12	0	9	22	0	1	3	6	1	3	34	23	0	5
Chlorococcales	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euglenophyceae Green	3	0	0	0	1	0	0	0	76	1	4	1	0	0
Euglenophyceae Colorless	0	0	0	0	1	1	0	1	1	0	0	0	0	0
Chrysophyceae	0	1	0	5	2	0	0	0	2	3	2	15	0	0
Cryptophyceae	22	8	26	50	20	33	50	81	3	28	28	10	20	42
Chloromonadinae	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Dinoflagellata	7	1	8	0	8	7	1	1	12	2	5	4	63	28
Bacillarieae	28	5	52	8	5	32	39	7	2	17	20	26	12	22
Zooflagellata	23	26	3	15	55	22	6	4	1	45	0	20	0	2
Infusoria	5	10	2	0	4	1	1	0	1	0	6	0	5	1
Rhizopoda	0	3	0	0	2	1	0	0	0	1	0	1	0	0

Table F-3

PER CENT OCCURRENCE OF EACH GROUP IN EACH SAMPLE AT STATION 4

	January		February			March	April	May		June	July		Sept.
Beggiatoales	0	0	1	0	0	3	0	0	0		0	0	0
Myxophyceae	0	0	0	0	0	1	0	0	0		0	6	0
Volvocales	5	4	0	0	13	6	6	1	10		5	16	20
Chlorococcales	0	0	0	0	0	2	0	0	0		0	0	0
Euglenophyceae Green	4	1	1	1	1	0	0	2	4		3	0	0
Euglenophyceae Colorless	1	1	1	7	0	0	0	1	1		1	0	0
Chrysophyceae	6	4	4	2	14	3	6	1	5		10	0	10
Cryptophyceae	13	17	35	10	9	16	39	26	12		12	25	10
Chloromonadinae	0	0	1	1	0	0	0	1	0		0	0	0
Dinoflagellata	2	0	15	0	0	0	2	2	10		3	10	7
Bacillarieae	23	42	15	46	47	50	39	55	39		48	35	45
Zooflagellata	30	30	7	23	15	18	3	2	15		9	0	4
Infusoria	1	1	10	0	1	1	5	4	3		3	8	2
Rhizopoda	15	0	10	10	0	0	0	5	1		6	0	2

Table F-4

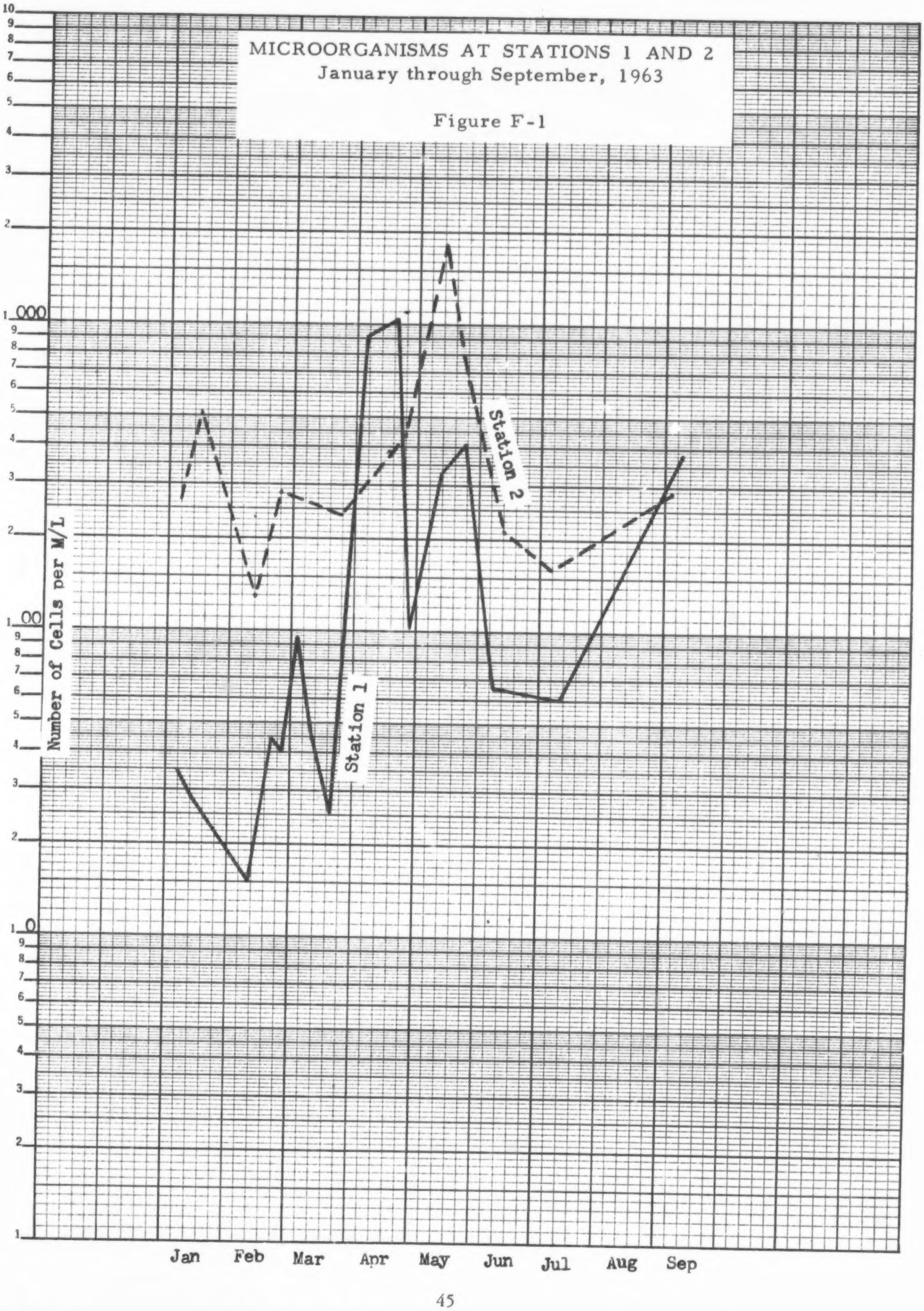
PER CENT OCCURRENCE OF EACH GROUP IN EACH SAMPLE AT STATION 6

	January	Feb.	March	April		May		June	July		Sept.
Beggiatoales	0		0	0	0	0	0	0	0	0	0
Myxophyceae	0		0	0	0	0	0	0	0	3	1
Volvocales	3		0	0	6	1	5	15	2	0	38
Chlorococcales	0		0	0	0	0	0	0	30	0	0
Euglenophyceae Green	0		0	0	1	1	12	3	1	3	0
Euglenophyceae Colorless	1		1	6	0	1	5	0	3	0	0
Chrysophyceae	9		3	3	1	4	5	0	5	0	9
Cryptophyceae	22		10	17	25	10	10	47	16	0	11
Chloromonadinae	0		1	0	0	3	0	0	0	0	0
Dinoflagellata	18		8	6	1	1	4	1	1	1	3
Bacillarieae	4		65	53	63	65	44	23	28	85	34
Zooflagellata	19		8	14	1	10	8	7	1	0	3
Infusoria	3		4	1	1	2	5	4	1	8	1
Rhizopoda	21		0	0	1	2	2	0	3	0	0

Table F-5

PER CENT OCCURRENCE OF EACH GROUP IN EACH SAMPLE AT STATION 9

	January		February		March			April			May			June	July			Sept.
Beggiatoales	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0
Myxophyceae	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0
Volvocales	10	9	1	4	2	0	0	0	1	4	1	3	1		0	1	30	0
Chlorococcales	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0
Euglenophyceae Green	0	1	0	1	0	0	0	0	0	0	0	0	1		0	0	0	0
Euglenophyceae Colorless	0	1	2	1	4	2	1	2	1	1	1	0	3		0	6	0	0
Chrysophyceae	4	14	22	4	0	0	3	1	10	2	2	0	1		1	10	0	5
Cryptophyceae	16	20	46	15	6	9	5	33	14	9	23	6	3		3	12	4	1
Chloromonadinae	0	1	0	0	0	0	0	0	0	1	0	0	1		0	3	8	0
Dinoflagellata	3	1	0	0	8	1	0	0	1	0	0	1	1		1	0	0	12
Bacillarieae	47	31	25	53	57	75	87	61	68	79	60	88	72		92	58	39	79
Zooflagellata	17	10	1	16	10	12	2	2	2	1	12	1	12		2	9	9	0
Infusoria	0	1	1	1	13	1	1	1	3	3	1	1	1		1	0	10	3
Rhizopoda	3	11	2	5	0	0	0	1	0	0	0	0	4		0	1	0	0



MICROORGANISMS AT STATIONS 1 AND 2
January through September, 1963

Figure F-1

that for many organisms there are records of occurrence in both fresh and ocean water. There is no clean separation.

The Salt Water Area. Station 6 and all subsequent stations (Figure I-3) are those of higher salinity. From these a much longer species list was recorded. They were more intensively studied as to biology. Fifty-seven of the recorded sixty blooms were in this area.

Qualitatively, the species list for this area is long but is strikingly lacking in dinoflagellates and plankton diatoms. Ciliates were few, and most of them were benthic, not planktonic forms, as was true of the diatoms. The principal interest in the salt water area is in the quantitative aspects of the biota.

The Biotic Groups

Sulfur and Iron Bacteria. Because so much of the estuary is shallow, it was expected that sulfide-reducing bacteria would be common among the suspended organisms. Table F-1 shows this frequent occurrence was not realized. In 221 samples there were found only five species of *Beggiatoa*, which occurred 17 times. Only two of these occurrences were at Station 1 or above. Iron bacteria were restricted to two recognizable species which occurred principally at Stations 1 to 4. This was expected because of the iron content of the ground water. The occurrence type for each of these bacteria is in accord with occurrences elsewhere. Normally, sulfur and iron bacteria offer little concerning the character of estuarine water and quantitatively are unimportant in this study.

Blue-Green Algae. Blue-green algae are likewise widely distributed over exposed muds, stones, and other objects, and upon macroscopic algae in tidal areas, so a large number were anticipated in this survey. Few were found.

Chlorophyceae. Almost every sample showed varying numbers of small green cells. Sometimes these were predominantly *Nannochloris;* sometimes *Chlorella;* sometimes *incertae sedis.* For very small cells such as these, species and even generic determination is almost impossible unless special studies are made. Therefore they were counted simply as small green cells. Aside from these, almost no Chlorophyceae were found. This is all the more remarkable in view of the macroscopic green algae, such as *Caulerpa, Codium,* and *Acetabularia crenulata,* which are present. Since none of the seven species found were ever abundant it may be said that, except for minute green cells, the Chlorophyceae were of no importance in the study.

Volvocales. Table F-1 shows the occurrence of 20 or more Volvocales. This group included only one non-green species, *Collodictyon triciliatum,* but the green members were uniformly small and while they may be regarded as characteristic of estuarine water of varying salinity, that is their sole significance in the Waccasassa Estuary. However, it should be noted here that *Thalassomonas* was found more frequently and in greater numbers in the Waccasassa Estuary than is usual. The group merits much taxonomic and ecologic study.

Green Euglenophyceae. Only 14 species were listed and only three of these were from the salt water area. Occurrence of all but two genera, Eutreptiella and Eutreptia, was very infrequent. Large numbers of either genus have been interpreted as indicating recent organic enrichment approaching pollution. This point will be discussed under the section on blooms. Actually the green Euglenophyceae were unexpectedly few and of no particular significance.

Colorless Euglenophyceae. The reverse situation held for colorless Euglenophyceae. Normally few of these are found in suspension since they are mostly creeping forms. The frequent occurrence (194 times) of the 36 colorless species indicates the effectiveness of the area currents in bringing these bottom-dwelling forms into suspension. Numbers are never very large, but this is because the population of colorless euglenids is largely confined to a water-sediment interface layer at best about 5 mm thick. In this layer they are numerous and of great variety. Saprozoic in nutrition, except for four or five species which are holozoic, they are very important workers there. This is an area of partial anaerobiosis and the oxygen demands of members of this group appear to be low. This is also the area into which particulate matter settles from above and where degradation of organic matter is probably most active, as evidenced by bacterial numbers, especially the sulfur bacteria, and numbers of ciliates. These colorless euglenids include five which are believed new to science and are being further studied. They are denoted by "p.n." in the extended Table F-1. The group probably represents one of major importance in this environment.

Chloromonadida. The organisms of this group are few in number (six) and of relatively limited occurrence. It is composed of species about which very little is known. The group, unimportant here, merits much more study.

Cryptomonadida. These few species are ubiquitous, or appear to be. In preserved material *Rhodomonas* is hardly separable from *Cryptomonas,* but the former is probably the most frequently occurring organism in the Waccasassa below Station 1. Nevertheless, because of its small size its biomass is small and it exerts little photosynthetic effect on the water. At no time have these organisms approached the numbers often found in fresh water lakes and rivers. They are probably of little importance here.

Dinoflagellata. Dinoflagellates were expected to occur in very large numbers and many species were anticipated.

This would be in accord with findings elsewhere (2) and even in the Gulf at other points where vast numbers of a single species occur in "red tides." Once more the expectation was not realized. Only 39 species were recognized, and 201 of the 359 occurrences were due to three small species. Oceanic dinoflagellates were virtually lacking, indicating that such waters as entered the estuary from the seaward side were greatly influenced by coastal contributions such as the Suwannee River.

Bacillarieae. Most of the diatoms were neritic and benthic forms which often could not be identified as to species. There were also plankton forms. Some species of *Navicula* occurred in almost every sample. The 71 named species are not inclusive, but the number of occurrences probably is close to actuality.

The diatoms easily made up the bulk of the chlorophyll containing microorganisms (Tables F-2 to F-5). This number both of species and of occurrences would also have been augmented by plankton net catches. The large round ones, 200 microns and more in diameter, and the often large colonies of *Nitzschia paradoxa* would have added materially to the biomass. One *Pleurosigma* in a sample is easily the equivalent of many *Rhodomonas* or *Dunaliella,* and it seems safe to say the diatoms must have been responsible to a great degree for any plankton photosynthetic effects. There were many epiphyric ones on attached algae, on copepods, and often on rocks and other fixed objects.

Rhizopoda. Among the distinctly animal forms, rhizopods were sparsely represented. There were no radiolarians and few Foraminifera or Heliozoa. Rare as they were, they included seldom-seen forms such as *Astrodisculus radians, Lithicolla flavescens, Nebela dentistoma,* and *Amphitreme stenostoma,* all of which would be of questionable occurrence in salt water, and *Paulinella chromatophora* from hard water sources. There is also one small testate rhizopod with a yellow shell which does not fit into any species whose descriptions are available, to which a provisional name, *Microgromia fulva,* has been given. It was the most frequent in occurrence of any of the rhizopods.

Zooflagellata. The small size of the zooflagellates and their habit of often attaching to debris by a long stalk permits them to be thrown into suspension quite easily. Fifty-one species were noted which occurred 877 times. Their small size also makes identification very difficult, which accounts for the 277 occurrences listed as unidentified zooflagellates. The group, if numerous, is important since most of them consume bacteria. The group includes a number which had not been previously seen and some of which either occur very seldom or are not observed readily. These are forms such as *Acanthoeca spectabilis, Dicraspedella stokesii,* and *Salpigacantha crennulata.* It also includes some believed to be as yet undescribed. The group merits further study so as to be well known. If there is such a thing as digestion of particulate matter under aerobic conditions while in suspension, these small flagellates would probably be the planktonic forms tending to keep bacterial numbers on the small flocs in the growth phase.

Ciliata. More species of ciliates (84) were found than any other group. Occurrences were moderate, a total of 595. Ciliates are large and easy to identify even if moving rapidly. The salt water ciliates are also rather better known (3) than the rhizopods and zooflagellates. The ciliates of the Waccasassa Estuary include 23 species, mostly tintinnids, which are usually termed plankton. But the remaining 61 are forms usually found at the bottom. In the Waccasassa their presence in the plankton is further confirmation of the current action in a shallow tidal estuary. While the planktonic forms tended to occur most frequently (282 times), the nonplankton forms occurred 306 times, enough to indicate a varied and numerous ciliate population in the water-sediment interface. Their role is manifestly that of keeping the bacteria in this layer at a high reproductive rate because most of them are known to consume bacteria. There are some which eat sulfur bacteria of various kinds. They constitute an interesting group and merit much study as to their significance in the ecology of the sea bottom. Some few are believed to be new undescribed species. None occurred in vast numbers but some means of obtaining numerical values for this population is needed.

Quantitative Aspects of the Biota

Numbers of microorganisms per ml were never very large. Since most of the species were of small size, especially those species which were most numerous, their biomass was extremely small. It should be remembered that certain organisms supposedly are indicative of pollution, if present in large numbers. A few species fit this definition but groups of certain species are more truly indicative. The first condition may be partly answered by what species occur as blooms and how frequently. Table F-6 is a list of organisms which occurred in excess of 500/ml (bloomed) in the Waccasassa studies with their stations and dates.

The unidentified Zooflagellata, *Monosiga ovata, Monas socialis,* and *Kephyrion ovum,* all being holozoic colorless flagellates and consumers of bacteria, might be indicative of pollution. However, they show no pattern of occurring in the upper reaches of the estuary where the pollution, if any, should be best defined. The remaining 41 blooms were all photosynthetic organisms, mostly diatoms. As such it is presumed their principal

Table F-6

ORGANISMS BLOOMING IN THE WACCASASSA IN 1963

Organisms	Dates	Stations – numbers per ml.									
		1	2	3	4	5	6	7	8	9	10
Amphiprora spp.	5/13						920		800	840	920
Chaetoceras spp.	7/2									1920	
Chlorophyceae (Unidentified)	8/25										800
Chrysophyceae (Unidentified)	6/25				516						
	7/10			2400	1600	1240					
Cyclotella meneghiniana principally	1/14			800							
	2/12			4800							
	4/23	500								600	
	4/29				560	1040	1200	1600	3040	1600	1040
	7/8										640
Detonula sp.	3/18								960	960	2400
	3/25									2400	5120
Eutreptiella hirudoidea	5/13		1440	600		1016					
Kephyrion oven	7/2								512		
Massartia rotundata	9/4		896								
Monas socialis	10/22	634									
Monosiga ovata	11/14					1024					
Nannochloris (atomus)	7/10				9600						
Navicula spp.	7/2								1080	640	640
Nitzschia closterium	7/2								640		
Pyramidomonas grossi	7/10			784							
Rhodomonas lacustris	3/25										608
	4/29						600				
	3/18										504
Thalassiosira spp.	7/2								896	11200	640
Zooflagellata spp.	1/14				1328						
	2/25									1024	
	4/29			800							
	6/11	840	800								
	6/25				516						
	7/2								640	1080	720
	7/8										800
	7/10				516	1200					

nutrients were inorganic salts. They do not indicate by their numbers any special enrichment in the bay.

Figure F-1 gives the occurrences of all organisms in 14 samplings at Station 1 in 1963. The total occurrence was 2337 organisms, an average of 233.7 per ml. Had it not been for one bloom of 634 minute zooflagellates (October 22, 1963), the average number would have been 170.3 per ml. The total individuals at Station 1 in 16 samples in 1963 were 3549, an average of 221.8/ml. Again, if a bloom of 504 small diatoms be excluded, the average falls to 190.3.

It appears from qualitative considerations that there is no great characterizing significance to the microbiotic population of the Waccasassa and its estuary. The species are simply those of a brown surface water system and an inshore shallow water marine population. Therefore the numbers might be critically examined for what relationship they show to other environmental characteristics such as pollution or its lack, salinity influences, and chemistry of the waters.

Total numbers have not been comparatively large during the present study although some high figures have been obtained on occasion. Thus in Figure F-1 the total numbers per ml at Stations 1 and 2 exceeded 1000 once and 500 once. The number dropped as low as 15 per ml once and almost all of these (90%) were colorless flagellates. Because the biomass of these zooflagellates is so small, it is questionable whether any effect can be accorded to the microbiota on this particular occasion. The average numbers per ml are low, especially if three blooms of *Massartia, Rhodomonas,* and *Eutreptiella* are subtracted before averaging. However, Stations 1 and 2 might be expected to have a low productivity. Figure F-2 presents the same information for Stations 8 and 10 near the estuary mouth. The average has risen to 858.2 individuals per ml. Once again the higher average is largely due to several blooms, principally very small diatoms. This is far below reports which showed 20,000/ml in Great South Bay (4).

This study deals largely with samplings in 1963. The occasional samples taken in 1962 do not indicate marked differences either in the groups present or in numbers. Table F-7 compares the two years at Station 1. The averages tend to smooth out high peaks caused by a bloom of a single species and to indicate what a normal population is like. When the blooms of certain species are omitted, the average number of organisms drops about 50 per cent.

The Dominant Groups

An inspection of Tables F-2 through F-5 would reveal that percentage wise the diatoms (Bacillarieae) are the largest group during the entire year, followed by the Cryptophyceae. This is true for all of the ten stations. For Stations 1 through 4 the second most abundant group consists of zooflagellates. For Stations 5 through 10 the zooflagellates share numbers with Chrysophyceae. This is to be expected. There are many small flagellated Chrysophyceae in upper ocean waters and perhaps fewer bacteria to serve as food for the zooflagellates.

The very low numbers of dinoflagellates, Coccolithophora, Silicoflagellata, Ebridiens, and tintinnid ciliates were quite unexpected. The last comprises an abundant offshore population, and while the variety was large the low population argues that either the water quality is not suitable or, more probably, the food supply (bacteria) is low.

No pattern of occurrence was particularly evident. Thus at Station 3 the high was in February, 1963. At Station 4 there were two population peaks (Figure F-2) in April and May, 1963, respectively. At Station 5 there was a high in April, 1963, and another in July, 1963. At Station 6 there were two population peaks, one in April and one in July. The high peak for Station 7 was in May. For both these stations small diatoms are the largest contributing group. These organisms seem to be best suited to the chemical extremes in the water of these two mixing stations. Organisms at Station 8 (Figure F-2) were mostly diatoms and showed a tendency not to drop below 400/ml. Despite peaks of about 4000 and 4800/ml, biomass was of necessity low because of the small size of the diatoms concerned. Almost the same statement could be made for Stations 9 and 10.

Plankton Tows

Copepods were present at Stations 8, 9, and 10 from March through July, 1963, in appreciable numbers with the exception of a single date, June 13. Their highest number was 87.11/1 at Station 8, June 24. On that same date there were only 3.74/1 at Station 10. Mollusks were few in number until the bay waters warmed up in May. Probably many of the univalve and bivalve shellfish spawned prior to May 20 and the swimming larvae appeared in the May net catches. Highest number was 6.68/1, July 15, at Station 8.

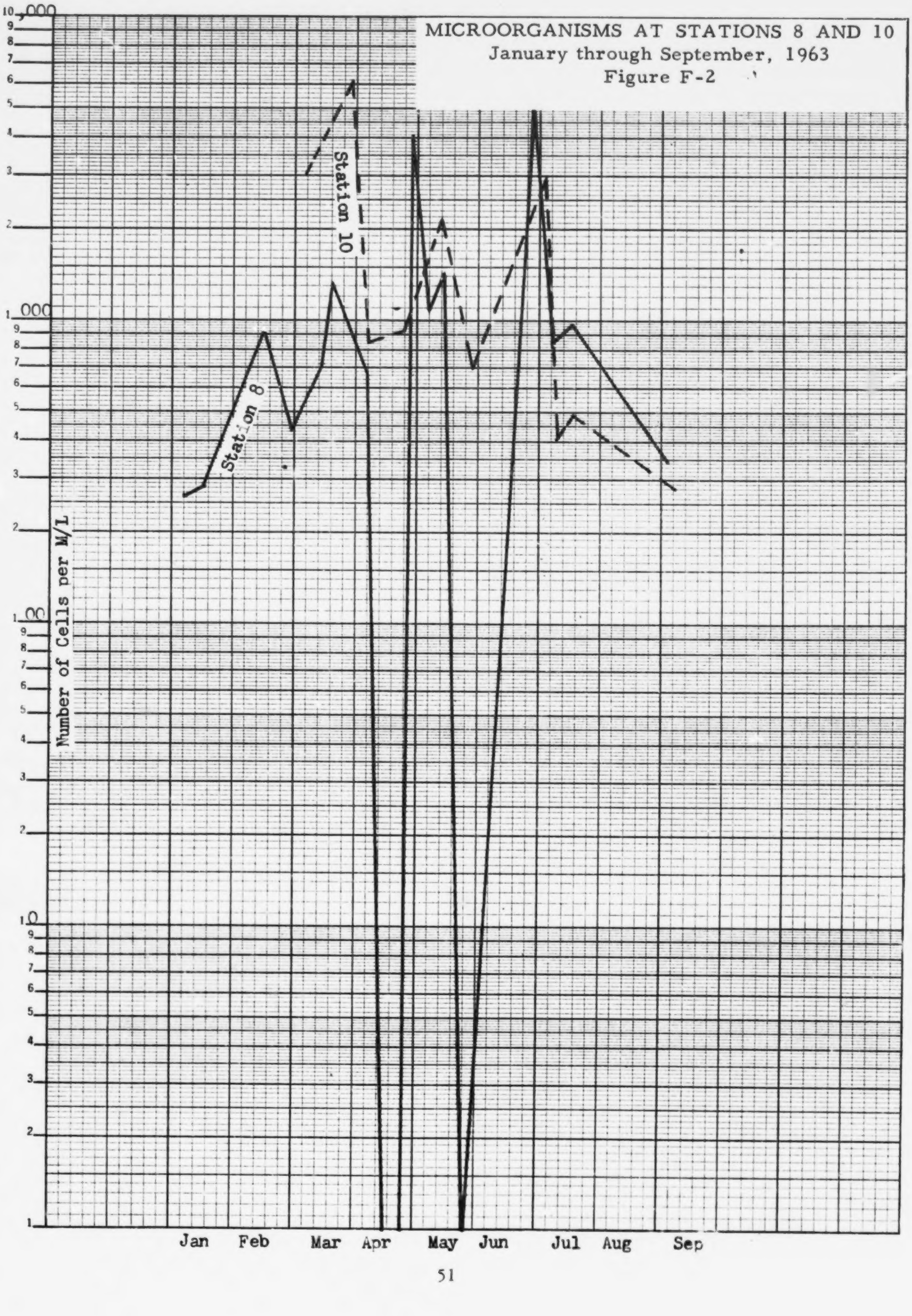
The potential predatory destruction of these combined grazers upon the microplankton must be high. To some extent this accounts for the low population in the bay. By, the same token fish, shellfish, and crustacean production should be dependent on macroplankton production. Unfortunately no figures are available on macroplankton counts in other areas of known productivity; no shellfish censuses were taken during this investigation, and while the bay is commercially fished for crabs and mullet, catches are unknown. Redfish sportfishing is prevalent in the winter but these fish are anadromous, migrating in from the Gulf. Large catches of small trash fish

Table F-7

THE NUMBER OF SPECIES AND THE POPULATION PER ML THEY REPRESENTED FOR 14 GROUPS OF MICROORGANISMS AT STATION 1 IN 1962 AND 1963

	No. Samples: 10 in 1962		No. Samples: 16 in 1963	
Organism Group	No. Species*	No. Organisms	No. Species*	No. Organisms
Sulfur bacteria	1	1	5	7
Blue-green algae	1	6	4	7
Volvocales	5	235	20	325
Chlorophyceae s.s.	2	28	6	8
Green Euglenophyceae	10	30	16	21
Colorless Euglenophyceae	2	2	9	15
Chrysophyceae	4	9	19	164
Cryptophyceae	20	358	40	1,506
Chloromonadida	1	1	3	3
Dinoflagellata	7	72	12	70
Diatoms	35	249	82	998
Rhizopoda	7	31	7	30
Zooflagellata	26	1,074	28	367
Infusoria	22	41	28	28
TOTALS	123	2,337	280	3,549
AVERAGES		233.7		221.3

*Not necessarily different species for both 1962 and 1963; simply the population in the samplings reported.



MICROORGANISMS AT STATIONS 8 AND 10
January through September, 1963
Figure F-2

(yellowtails, catfish, shiners) are a nuisance and small speckled trout feed in the bay in great numbers. None of these speculations is statistically supported but they indicate an estuary wherein primary production is low to moderate, where no extreme conditions occur commonly, and where biologic balance is good.

Suspended Slide Studies

An interesting experiment with the suspended slide technique developed the data shown in Table F-8. The readiness with which these slides were colonized suggests that the water is sufficiently enriched to support certain large populations, but that a proper substrate is necessary, and that the more closely living conditions are examined, the more organisms one encounters.

Sediment-Water Interface Studies

Quantitative studies of certain bacteria, the algae, and the protozoa living in the thin flocculent sediment-water interface material are very difficult. In the Waccasassa Estuary the bottom may be bare rock, shell debris, sand, or silt. The best samples are from cores taken

Table F-8

ORGANISMS NOTED ON SLIDE SUSPENDED IN THE WACCASASSA ESTUARY FOR VARIOUS PERIODS

Areas counted: 625 sq. mm.

Depth: two feet or more

	Station 6	*Station 8*
Hours suspended	96	72
Organism	***No.***	***No.***
Ciliata		
Aspidisca costata		64
Chilodonella cucullulus	356	
Cothurnia sp.		16
Dysteria oliva	16	16
Holosticha rubrum	16	
Lionotus cygnus	100	
Oxytricha sp.	64	
Peritromus californicus		16
Trochilia sigmoidea	16	
Zoothamnium, colonies	52	
Vorticella sp.	16	
Rhizopoda		
Amoebulae	x	x
Cienkowskia mereschkowskia	x	x
Zooflagellata		
Bicocca lacustris	x	x
Bodo agilis	x	x
Bodo caudatus	x	
Pleuromonas saltans	x	x
Pteridomonas pulex	x	
Salpingoeca marssoni	x	
Volvocales		
Chlamydomonas sp.		x
Dunaliella cordata		x
Pedinopera granulose		x
Euglenophyceae		
Dinema grisoleum		x
Notosolenus apocamptus		x
Triangulomonas rigida		x

Table F-9

THE SPECIES OF GENERA OF 13 MICROBIOTIC GROUPS FOUND IN 18 CORE SAMPLES FROM WACCASASSA ESTUARY STATIONS, AND THE NUMBER OF OCCURRENCES IN THESE SAMPLES

Numbers per ml are not given but are available for some cores

Organism Group	*No. Species Found*	*No. Occurrences*
Bacteria (Sulfur group)	6	15
Blue grean algae	5	9
Volvocales – green flagellates	4	18
Euglenophyceae – green	1	2
Euglenophyceae – colorless	27	68
Cryptophyceae – mixed	4	19
Chrysophyceae – mixed	3	6
Dinoflagellatae – mixed	8	12
Chloromonadida – colorless	2	8
Diatoms – green	35	96
Rhizopoda – colorless	8	11
Zooflagellata – colorless	16	51
Ciliata – colorless	39	81
TOTALS	158	396

in a clear plastic tube in which the core does not reach the top of the tube. Table F-9 shows the genera and/or species of 12 microorganism groups found in the sediment-water interface of 18 Waccasassa cores, all taken near Stations 6, 8, and 10. This large number includes only 12 of the 25 organisms found on slides (Table F-8) but practically all organisms in both tables are creeping and crawling types. There are indications that there are three distinct microbiotic habitats in the Waccasassa Estuary, viz., the plankton; the benthic forms in the aufwuchs (organisms on plant stems, leaves, and macroscopic vegetation generally); and the benthic forms of the sediment-water interface. It is further indicated that the chlorophyll-containing forms in the benthos probably include many individuals whose specific gravity or loss of hydrostatic adjustment mechanism causes them to settle, unless resuspended by current action, and to be buried there to decompose. For example, no diatoms were found on the suspended slides even after 96 hours, whereas 35 species or genera of diatoms were found in the cores along with vast numbers of diatom shells.

The intense biologic action postulated for the sediment-water interface occurs in a thin layer 2-5 mm in thickness. Nevertheless, whatever organic matter becomes trapped in this layer finds a large population there to degrade it. This, of course, does not compare with the potential of degradation due to plankton in a water column two meters deep. There has been virtually no evidence of plankton stratification in the Waccasassa Estuary. It is inferred that the plankton population is the same in any milliliter from top to bottom. Figure F-2 shows that in May, 1963, there were about 1200 plankters per ml at Station 10. In a water column two meters deep and one mm on a side there would be 2,400,000 algae and protozoa active in mineralization, or 240,000 times as many as in the interface layer. The situation is a very complex one, however; many of the plankters are photosynthetic, acting on PO_4, NO_3, and other salts; the predators are low in the plankton; the interface organisms may be large in size compared to the plankters; much organic matter may be completely mineralized without ever settling out of suspension.

The work done in these thin bottom sediments is impressive. Decomposition of organic matter must be partly aerobic in the seas. Any particle which requires a long time to reach the bottom is under constant oxidative attack while freely suspended in the water. If and when it reaches the bottom it may sink into the black anaerobic layer of mud, where its decomposition is greatly slowed. Or it may rest in the brown aerobic layer. There, in addition to the bacteria, the saprophytic colorless Euglenophyceae attack it; the ciliates utilize the bacteria as food and maintain the active bacterial reproductive cycle. Altogether this sediment-water interface merits much more study than has been accorded it in the past. In addition, there should be some enumeration of the shellfish and worms in the bottom muds.

The Macroscopic Vegetation

Mention has already been made of the submerged and emergent vegetation growing in the headwaters and in the main river to within a short distance of Station 1. From this point until beyond Stations 6 and 7 there are no growths. But the area from South Point seaward and east of a line to Station 9 is heavily colonized by large *Sargassum* plants, along with dense beds of *Gracilaria*. This area is locally termed speckled bottom because where there is silt, the bottom is bare. The best growths of grass occur in patches of sand, while the algae, green, brown, and red, are attached to the solid bottom.

The large standing crop of macroscopic red and brown algae should be very effective in removing nutrients, e.g., PO_4 and NO_3, from solution. Once removed, these substances tend to stay locked up in the plant for a long time. Competition from the rooted grasses, principally *Zostera, Thalassia,* and *Diplanthera,* is also important because these take nutrients from the bottom sediments which otherwise would be recycled to the water above. The major parts of these die in the winter and their chemicals are released at that time by decomposition.

The Waccasassa Environment

This estuary insofar as its biota is concerned gives no indication of being polluted. Chemical data show no oxygen sag and the BOD values are better than those for many fresh water streams. Evidently there is little decomposable organic matter in suspension and in the bay proper there are large patches of bare sand and rock, while the few bottom samples indicate no sludge, but where there is mud it is a mixture of sand and well-mineralized matter.

Aeration and photosynthesis evidently proceed apace above Station 1. Since the DO never falls below 75 per cent saturation there is no danger of anaerobiosis and the loss of any of the animal population. In the lower stations wind action becomes a factor and on the flats there is a good standing crop of macroscopic plants, so reaeration is no problem.

The crop of photosynthetic plankton is small, however, and both O_2 production and glucose production are low. Furthermore, there is a very evident failure of light penetration. Secchi disc measurements of 24, 36, and 48 inches are common. The major effect would be to decrease photosynthesis, hence reaeration.

The rise in total nitrogen at the outer stations may reflect several causes. One is an increased animal population. No census has been taken, but the schools of small fish are far more abundant there than inshore from Stations 6 and 7. The copepod crop discussed above is also more abundant there as are mollusk, worm, and other crustacean larvae. Oysters on the reefs are densely packed and smaller mollusks such as whelks are also plentiful.

These statements are deduced from averaged chemical results. The principal conclusion which can be drawn is that there is very little correlation between the chemistry of the water and the biota present. The principal agreement is between the low BOD values and the small biomass of organisms present.

Normal nitrate-phosphate ratios would be about 10/1 for plant life. Nothing like this was found. For a 10/1 ratio, 1.24 mg/l of NO_3 would have been required, about 82 times as much as was actually present. Values for both, as well as for ratios, varied widely. No pattern could be ascertained beyond stating that NO_3 was consistently low and that PO_4, sometimes most abundant in the headwaters, sometimes below Station 2, was always abundant in the bottom samples.

Total organic nitrogen reflected rather well the suspended microbiota. This is logical and if a greater plankton crop had been present, still higher values might have occurred. In general, its lowest values were at Stations 101, 102, and 103. This is where the fewest plankton organisms were found.

Changes in Salinity

In subsequent sections of the report it is shown that salinity values as affected by wind and tidal action fluctuate widely. This might be expected to influence the distribution of the plankton. Organisms closely adapted to fresh water (and also those with a similar reaction to a definite salinity range) might be adversely affected by these changes. However, there are few in either category in the Waccasassa. Most of the organisms in the estuary exhibit a wide tolerance. There is little chance that abrupt tidal changes in the composition of water at a particular place would affect the distribution of such species. The prevalent organisms were widely dispersed and quickly mixed from one water mass to another. Bottom forms, if salinity conditions become adverse, simply retreat into the mud, or, like the oyster, shut up shop.

Decomposition of Organic Matter in the Sea

In this unpolluted estuary whatever organic matter is decomposed must be the plant and animal debris largely originating in the estuary. While the river water is brown when it enters the estuary, its low BOD indicates a paucity of decomposable matter. In the estuary itself there is an annual die-off of the grasses and larger algae so that it would be possible for large amounts of dead matter to exist in areas free from current action. If sludge banks formed in such areas, decomposition there would be anaerobic. It seems probable, however, that in this estuary, shallow and current swept, much decomposition occurs while organic particles are in suspension and subject to aerobic decomposition. Nevertheless, the course of anaerobic decomposition is important because it is slow, and in a polluted estuary the pollutants would be superimposed upon the natural organic debris. Also, it is known that some seaweeds are slow to decompose so that any accumulation augments the problem.

Discussion

The foregoing study of the biologic situation in the Waccasassa and its estuary has shown a stream which contributes few microorganisms to the estuary, and an estuary which is invaded by few plankters from the open Gulf. It therefore has an indigenous population, low in biomass at the second trophic level but which at times blooms rather abundantly. The reasons for its low biomass are complex, but contributing factors are a low nutrient level, an unbalanced nitrogen-phosphorus level, possible predation by copepods and mollusk larvae, competition for nutrients by the large crop of attached algae and grass, and at times turbidity. The large number of species listed shows a potential for great numbers of organisms, and it is believed that the low nutrient level is the principal limiting factor. Rainfall records (Table D-1) show a 13-inch deficiency during 1963, so nutrient-containing ground water contributions were low during the survey. In addition, surveys of the headwater areas show little sources of PO_4 and NO_3 from arable or heavily pastured land.

As matters stand, the estuary is primarily a recreation area for a portion of each winter, and then for a few (comparatively) redfish fishermen and hunters. There is also some trout fishing on the flats beyond the estuary. Commercial fishing is largely limited to mullet and to crabs.

But there is another question – whether or not such an area can be made more useful to an expanding population and what changes can be made while still retaining the useful characteristics of the estuary; aesthetic, piscatorial, and otherwise. Since waste disposal adds fertilizing materials, any increase of these in the Waccasassa is certain to greatly increase productivity. There is sufficient light and a favorable temperature for this. The very fluctuations in salinity instead of being restrictive tend to augment the population. The shallowness of the whole area tends to rapid oxidation, aided by the current action. There are no deep basins where biologic action would be slowed up. It seems that this area could very easily develop nuisance conditions unless kept free of undue fertilization. At the same time some enrichment of an estuary such as this could be beneficial.

Whether or not this is a "normal" or a subnormal estuary is an open question. Its water is certainly of good quality. It is a pleasant spot for the aesthetically minded and there are no nuisance growths in it at present. It is expected that productivity in the Waccasassa would be low because of the small standing crop of phytoplankton. Nevertheless, there is always the problem of benthic production for which we have no measurements in the Waccasassa. It may be that the low productivity here is a limiting factor for oyster size and shrimp abundance, and enrichment of the bay would be a benefit up to a certain point. If this should come about, we at least have advance data. The work on the Waccasassa should give us a reference point, at least until we find out how typical it is. Biologically it seems rather good in this respect – low in nutrients and unbalanced in its ratios. It is unpolluted and has some similarities to other west Gulf Coast estuarine situations.

G. PRIMARY PRODUCTIVITY

Introduction

Domestic and industrial wastes are discharged into coastal waters with increased frequency in nearly every part of the world. This is cause for concern particularly since the effect of these substances on the marine ecosystem is not well understood. This especially applies to estuaries where the biotic system is greatly influenced by the mixing processes of saline and fresh water. More basic information is needed concerning the biology of estuaries since the effluents from communities are leading to serious pollution problems in some areas.

The synthesis of organic matter by photosynthetic organisms, referred to as primary production, is a biological parameter which may serve as a guide to the fertility of an estuary. Furthermore, primary productivity measurements if made over a sufficient length of time can be valuable as an indication of the rate of eutrophy. In this way, effects of wastes on the biota of the estuary can be assessed continually and changes which occur in the ecological balance noted.

Productivity studies were begun in the Waccasassa Estuary during late October, 1963, and were continued intermittently through August, 1965. Since this estuary receives no appreciable wastes of any kind from human sources, phytoplankton production is that of an unpolluted, subtropical, brackish water environment. The lower part of the estuary is relatively shallow with a mean depth of three to five feet. Unless turbidity is greatly increased by wind-generated turbulence, light penetrates to the bottom enabling the suspended algae and attached vegetation to carry on photosynthesis. Furthermore, due to the shallowness and complete mixing by wind, mineralized nutrient material in bottom sediments is metabolically recycled fairly rapidly by phytoplankton. The physical features of shallow depth greatly enhance the productivity potential of the estuary because of the rapid exchange of nutrients from the bottom and the penetration of sunlight.

Methods

Primary productivity measurements were made principally by the *in situ* technique employing isotopic carbon-14 developed by Steemann Nielsen (1). The isotope was in the form of sodium carbonate and was obtained in the standard 4 microcurie ampule from the International Laboratory for Marine Productivity Determinations at Charlottenlund-Slot, Denmark.

When productivity was measured, paired light and dark bottles containing estuary water charged with carbon-14 were suspended from a line at two or more depths. Usually four stations were occupied in this manner. The bottles remained in the water under natural illumination for a period of four to six hours beginning near 0900. The bottles were then retrieved and formalin added to the contents. Filtration of the sample aliquots was completed at the Phelps Laboratory using a one-inch diameter membrane filter with a pore size of 0.45 microns.

Filters with the adhering mat of plankton were dried in a desiccator and counted. Jenkins (2) has outlined the procedure recently for measuring productivity in turbid water.

Ancillary analyses for pH, carbonate content, and chlorides were by Standard Methods procedures (3). Calculation of total carbon dioxide content followed that of Strickland (4).

Calculation of total carbon fixation per hour was based on the formulas of Doty and Oguri (5), and values were expressed in terms of daily production by reference to tables of sunrise and sunset of the American Ephemeris (6).

The bioassays for limiting growth substances completed to this time followed similar work reported by Ryther and Guillard (7) and Menzel and Ryther (8) in the Sargasso Sea. The technique is discussed in papers by Provasoli (9) and Goldman (10) and recently reviewed by Belser (11). Bioassay of the Waccasassa Estuary water was done in 250 Erlenmeyer flasks. The medium employed for this purpose is given in Table G-1.

Various component additions of growth substances were added to flasks of lower estuary water. The flasks were placed in a lighted incubator to equilibrate at 750 foot-candles for 24 hours at 20°C. Then they were charged with labeled carbonate. After a four-hour exposure period, formalin was added to the contents of the flasks to stop photosynthesis and the contents membrane filtered as in the *in situ* procedure. A substance was considered to be limiting photosynthesis if its omission from the nutrient medium reduced isotopic carbon fixation.

Table G-1
MEDIUM COMPOSITION FOR BIOASSAY OF ESTUARINE WATER

Substance	***Concentration***
$NaNO_3$	50 microgram atoms N/l
$Na_2HPO_4 \cdot 12H_2O$	5 microgram atoms P/l
$Na_2SiO_3 \cdot 9H_2O$	50 microgram atoms Si/l
$Na_2S_2O_3 \cdot 5H_2O$	8 microgram atoms S/l
Vitamin Mix	
Thiamin HCl	0.2 mg/l
Biotin	1.0 microgram/l
B_{12}	1.0 microgram/l
Trace Metals	
Fe	1.30 mg F/l
$CuSO_4 \cdot 5H_2O$	0.005 mg Cu/l
$ZnSO_4 \cdot 7H_2O$	0.010 mg Zn/l
$CoCl_2 \cdot 6H_2O$	0.005 mg Co/l
$MnCl_2 \cdot 4H_2O$	0.100 mg Mn/l
$Na_2MoO_4 \cdot 2H_2O$	0.005 mg Mo/l
EDTA	1.0 mg/l

Samples for plant pigment determinations were collected from upper and lower estuary stations. The method used for these analyses was developed by Richards with Thompson (12) and Crietz and Richards (13). Absorption readings of the acetone extracts were made with a Beckman DU Spectrophotometer.

A Fortran computer program was developed for the IBM 709 which allowed computation of all plant pigments plus a statistical analysis of the resulting data. This program shortens the time required for computation in excess of 95 per cent and should enhance the use of the spectrophotometric method in the future.

Results

A substantial number of primary productivity measurements was made in the estuary.* They varied from a minimum of 1.1 mg of carbon/m^3/day at Station 2 in March, 1964, to a maximum of 2.7 gms/m^3/day in surface water at Station 10 the beginning of October of the same year. Photosynthesis in this estuary was highest during June and early October. An inspection of Figure G-1 shows these seasonal differences in productivity. From a low of 25 mg/m^2 in January, daily carbon fixation gradually increased to 761 mg/m^2 in June.† Productivity,

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*A tabulation of these is included in the separate Section G report.

†Carbon fixation expressed as mg/m2 usually denotes that amount of primary productivity occurring on an integrated basis throughout the water mass. That amount of productivity expressed in volume units (m^3) denotes the photosynthesis occurring at a specific depth interval.

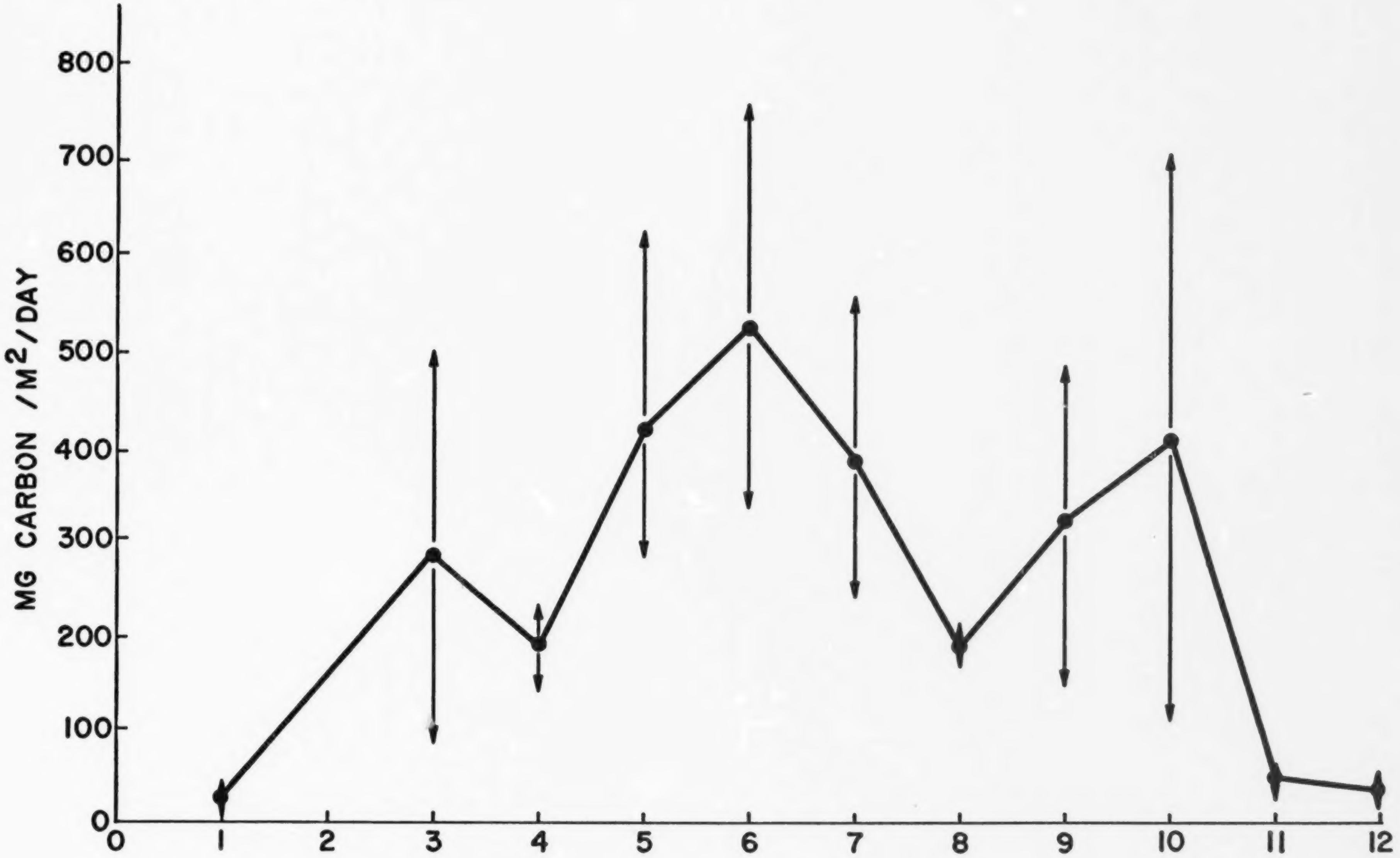

Figure G-1

Monthly Average and Range of
Integral Photosynthesis in Waccasassa Estuary

following the early summer peak, declines until early October when a fall maximum may be noted. This increase in production during autumn often is observed in phytoplankton growth patterns.

Primary productivity in surface water increased downstream, progressing from Station 2 to Station 10. Mean surface values between these stations ranged from 44 to 557 mgC/m^3/day. This difference amounting to an order of magnitude shows the relative fertility of water in the upper reaches of the estuary from that in the lower reaches.

A comparison of the values with those from other marine areas outlined in Table G-2 shows the Waccasassa Estuary (394 mgC/m^3/day) to be generally as productive as these coastal waters. Inshore waters of the Waccasassa are more fertile than those reported for the east Gulf of Mexico (approximately 50 mgC/m^3/day and the Gulf Stream (30 mgC/m^3/day).

This level of productivity in the Waccasassa generally conforms to Odum's concept of the fertility of estuaries which he considers to be one of the world's most productive areas. Average rates of gross production may be as great as 10-25 gms of dry matter/m^2/day. On a comparable basis, shallow lakes and agricultural areas average only 3-10 gms/m^2/day.

Estuaries as Nutrient Traps. It has been shown by Redfield *et al.* (14) that estuarine systems can function as a nutrient trap by differential advection and thereby enrich the water with growth substances for microorganisms. Although the nutrients accumulated at different rates, these workers found that fertility was dependent on rate of production of organic matter, length of basin, turbulence, velocity of flow, and relative depth. The synthesis of organic materials and basin length were found to be positive factors, while the others were considered to function in a negative way.

In the Waccasassa Estuary increased productivity of phytoplankton is discernible between Stations 6 and 10, where the estuary widens to an embayment. Considering the bay as the most fertile area of the estuary, then productivity will be low in upper estuary stations, increase to a maximum at the mouth, and decrease in the Gulf of Mexico.

Such a productivity pattern, where maximum amounts were recorded at lower estuary stations, was observed during the different phases of the project. Station 10 was used in these cases to approximate the Gulf environment since it was located at the outer boundary of the estuary. Figure G-2 shows the general nature of productivity distribution in the Waccasassa Estuary when these conditions were applied. Using probability theory, where chances are computed that a set of events will or will not occur, it was found that the probability of primary productivity reaching a maximum between Stations 6 and 8, and then decreasing at Station 10 at any randomly chosen date was 0.69 at an interval of 95 per cent confidence. However, later observations at a station farther into the Gulf have shown that in eight out of ten experiments productivity was lower here than in water at Station 10. Using this data somewhat speculatively and designating Station 10 as an area with bay characteristics, the probability that primary productivity will be a maximum at Stations 7, 8, or 10 is increased to 0.93. This means that photosynthesis will be higher in the bay than in either the river or the Gulf 93 per cent of the time during the year when estimates are made.

However, using this same system, chlorophyll *a* patterns exhibit an effect opposite to that obtained in productivity. Figure G-3 shows that the probability of plant pigment or standing crop showing a minimum in the river and a maximum in the bay is 0.39. The more usual pattern (P = 0.60) is one where no clear prediction can be made concerning maxima except at the outer bay and upper reach of the river.

Oxygen Production by Phytoplankton. In the past several years interest has been renewed regarding the role of phytoplankton in the reaeration of surface waters. Papers by Hull (15) have indicated that phytoplankton contributed significant quantities of oxygen by photosynthesis, and he estimated that 600,000 pounds/day were produced in Baltimore Harbor during August. As a basis for comparison, carbon fixation values for Waccasassa Bay were converted to equivalent oxygen. Oxygen production in pounds per day ranges from a minimum of 1,021 in January, 1964, to a maximum of 30,790 in June, 1965 (Table G-3). The difference between the amount of oxygen reported by Hull for Baltimore Harbor and that for the Waccasassa is approximately an order of magnitude. Scattered observations by Hull showed no oxygen production at all in Baltimore Harbor during the winter.

In a study of the eutrophication of the Forge River Estuary on Long Island, Barlow *et al* (16) reported gross oxygen production in mg/m^2/day from 1,050 in March to 14,025 during August. Maximum production of oxygen in the Waccasassa was 2027 mg/m^2/day. On a comparable basis to the Forge River, this Florida estuary is oligotrophic.

Plant Pigments. Measuring plant pigments has become a routine analysis in production studies as an index of the fertility and the standing crop of phytoplankton. Table G-4 summarizes the chlorophyll data obtained during the study of the Waccasassa Estuary. It is evident in a comparison of means that chlorophyll *a* increases downstream from Station 2 reaching a maximum of 13.29 mg/m^3 at Station 8 at the estuary mouth.

The mean values for all stations (n = 415) are chlorophyll *a*, 11.95 mg/m^3; chlorophyll *b*, 4.05 mg/m^3; chloro-

Table G-2

PRIMARY PRODUCTION VALUES OF SELECTED MARINE AREAS

Place	*mgC/m^3/day*
Long Island Sound	20-300
New England Coastal Waters	250
East Gulf of Mexico	50 (Approximate)
Gulf Stream	30
Puget Sound	300 (Approximate)
Narragansett Bay	250
Sargasso Sea	20

From Strickland Table IX, *Measuring the Production of Marine Phytoplankton* (1960)

Table G-3

PRIMARY PRODUCTION WACCASASSA ESTUARY

Date	*mgC/m^2/day*	*Total Carbon Fixed mg/day × 10^6*	*Oxygen Production mg/day × 10^6*	*Oxygen Production mg/m^2/day*	*Oxygen Production pounds/day*
10/29/63	116	799	2,132	309	4,701
11/6/63	34	234	625	91	1,377
11/20/63	64	441	1,175	171	2,591
12/18/63	48	332	884	128	1,950
1/16/64	25	174	463	67	1,021
3/4/64	86	593	1,578	229	3,479
3/17/64	502	3,459	9,212	1,337	20,309
4/8/64	151	1,040	2,770	402	6,107
4/22/64	232	1,599	4,258	618	9,387
5/12/64	438	3,018	8,041	1,167	17,727
5/27/64	620	4,272	11,383	1,652	25,095
6/29/64	761	5.243	13,966	2,027	30,790
9/3/64	483	3,328	8,868	1,287	19,551
9/24/64	165	1,137	3,032	440	6,684
10/1/64	710	4,892	13,029	1,891	28,724
5/4/65	292	2,012	5,361	778	11,819
5/17/65	352	2,425	6,463	938	14,248
6/1/65	598	4,120	10,976	1,593	24,198
6/14/65	405	2,790	7,434	1,079	16,389
6/28/65	345	2,377	6,332	919	13,960
7/13/65	257	1,771	4,713	684	10,390
7/19/65	566	3,900	10,390	1,508	22,906
7/26/65	362	2,494	6,642	964	14,643
8/13/65	195	1,344	3,576	519	7,883
8/23/65	193	1,330	3,542	514	7,809

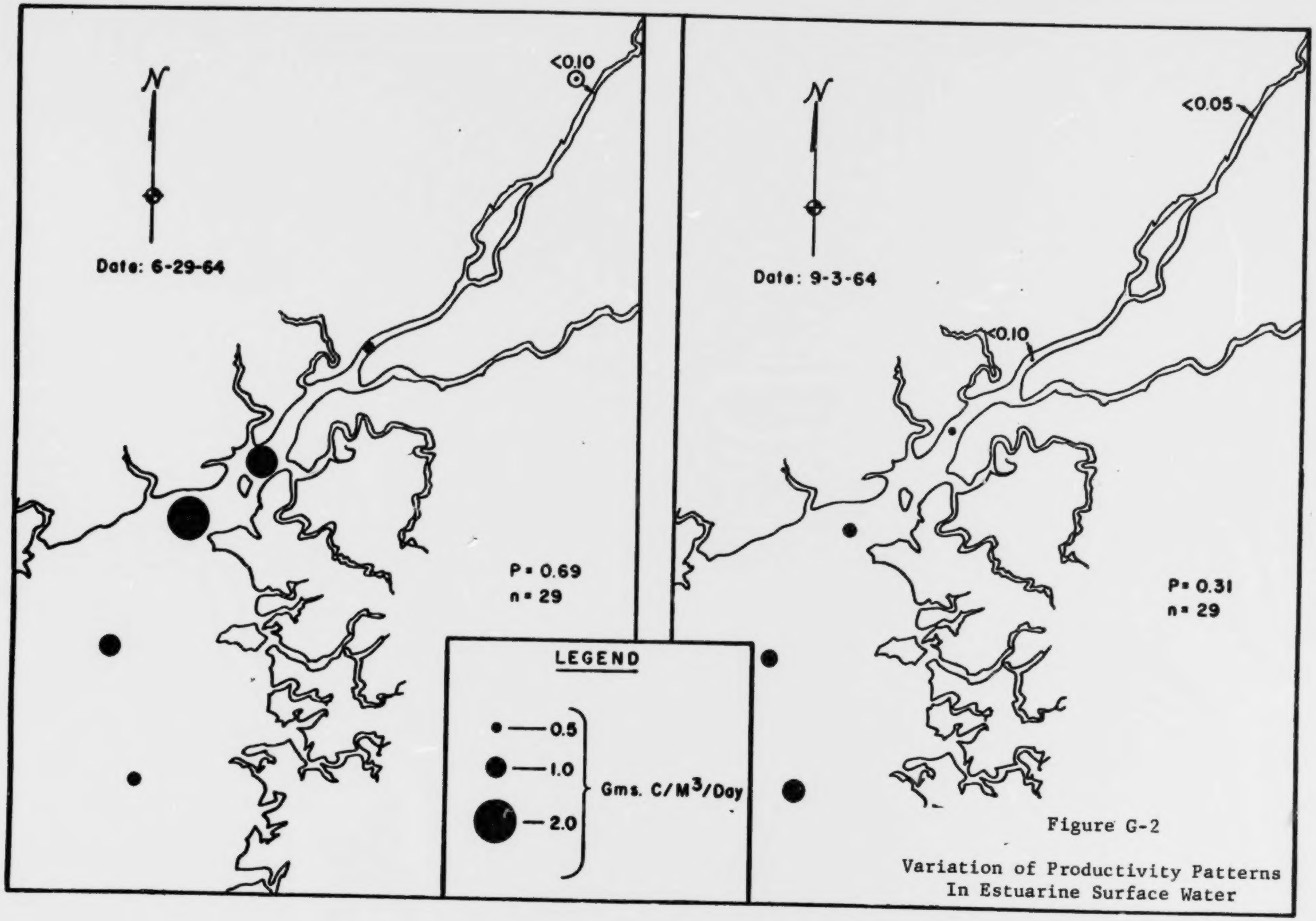
N
Date: 6-29-64
<0.10
P = 0.69
n = 29
N
Date: 9-3-64
<0.05
<0.10
P = 0.31
n = 29
LEGEND
0.5
1.0
2.0
Gms. C/M³/Day

Figure G-2

Variation of Productivity Patterns In Estuarine Surface Water

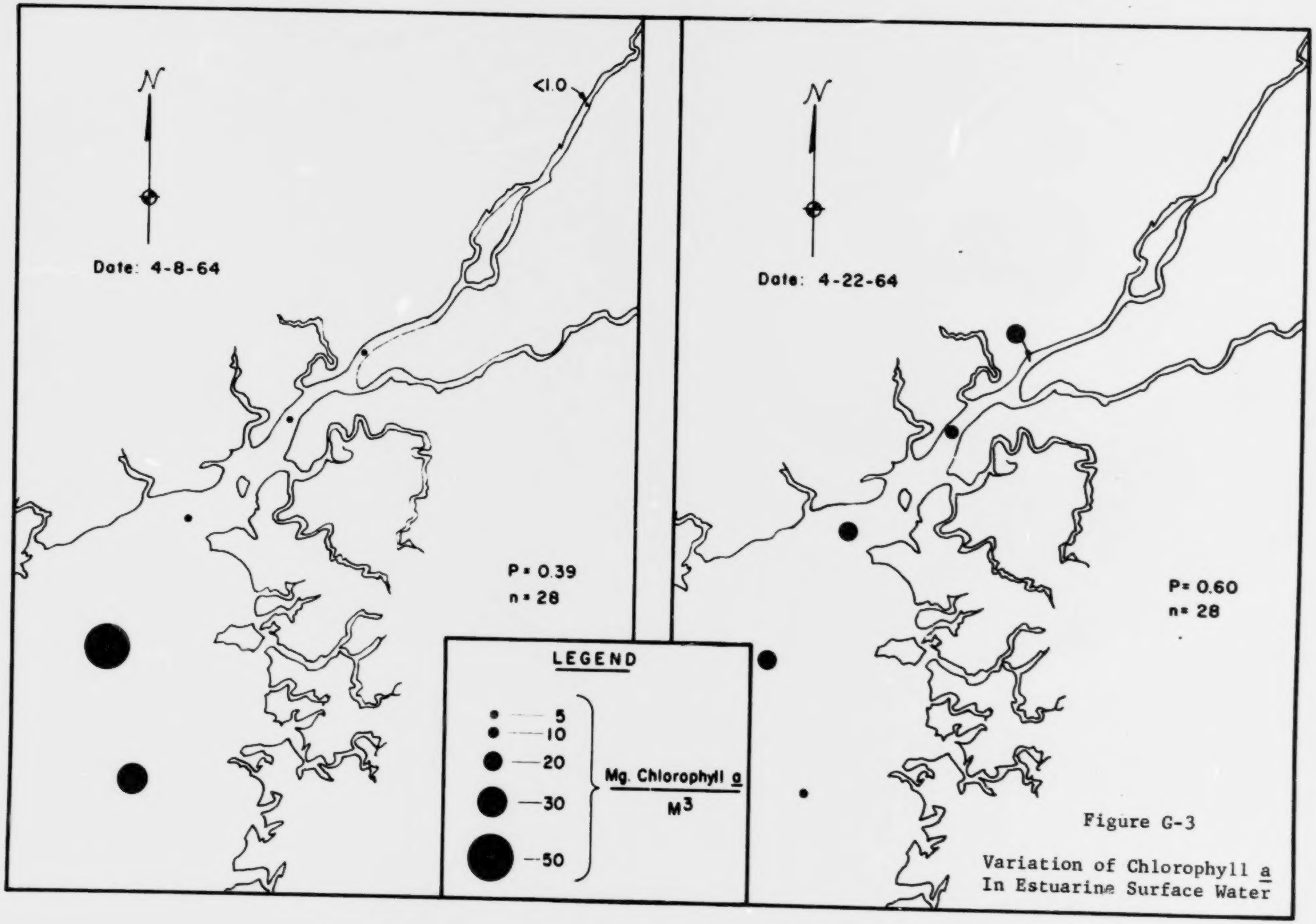
N
Date: 4-8-64
<1.0
P = 0.39
n = 28
N
Date: 4-22-64
P = 0.60
n = 28
LEGEND
5
10
20
30
50
Mg. Chlorophyll a / M3

Figure G-3

Variation of Chlorophyll a
In Estuarine Surface Water

Table G-4

MEAN VALUES FOR CHLOROPHYLL *a* IN ESTUARINE WATER (Mg/M^3)

Month	*Station* 2	4	6	7	8	10	*Monthly Mean*
Jan.	4.52	3.51	3.02	5.64	3.88	4.24	4.14
Feb.	0.78	1.03	1.12	1.39	3.45	2.42	1.70
March	1.25	2.43	9.31	28.28	14.76	9.72	10.96
April	0.50	10.53	5.48	12.24	38.82	19.61	14.53
May	3.39	7.02	6.71	6.47	12.26	11.35	7.86
June	2.48*	6.28*	7.07*	31.06	30.66	33.92	18.57
July	1.57	5.54	7.43	17.08	21.26	13.91	11.13
Aug.	0.59	2.18	5.77	10.72	11.88	17.38	8.09
Sept.	1.18	3.48	3.21	3.70	9.94	10.50	5.34
Oct.	-	-	-	4.84	5.35	5.85	5.35
Nov.	-	-	3.56	3.94	2.71	2.36	3.14
Dec.	0.50	2.04	3.13	3.31	4.46	3.20	2.77
Mean:	1.396	3.67	4.65	10.72	13.29	11.20	

Footnote

Mean values all stations:

Chlorophyll *a*	11.95 mg/m^3
Chlorophyll *b*	4.05 mg/m^3
Chlorophyll *c*	14.27 mspu/m^3†

N = 415

*Estimated value

†Richard's millispecial pigment unit

Table G-5

BIOASSAY FOR LIMITING GROWTH SUBSTANCES IN WACCASASSA ESTUARY – MARCH 4, 1964

Addition	*cpm partial/cpm complete supplement/supplement*
Control (no addition)	0.856 $\frac{\text{(control)}}{\text{(complete)}}$
Complete medium	1.00 $\frac{\text{(complete)}}{\text{(complete)}}$
Complete medium less NO$_3$	0.118
Complete medium less PO$_4$	0.444
Complete medium less NO$_3$, PO$_4$	0.228
Complete medium less Fe	1.08
Complete medium less Fe, NO$_3$, PO$_4$	0.148
Complete medium less trace elements	0.741
Complete medium less trace elements, EDTA	1.03
Complete medium less vitamins	0.878
Complete medium less silicon	1.17

phyll *c*, 14.27 mg/m^3. The standing crop for the estuary is lowest at the upper estuary Stations 2 and 4 and increases downstream reaching a maximum at Stations 7-10. The pigment levels in the water decline beyond Station 8 and presumably reach a minimum in the Gulf some distance from Station 10.

Maximum pigment values occurred in April, 1964, during a period of high southwesterly winds. This wind velocity caused extreme water turbulence in the shallow estuary area. Secchi disk readings, for example, were only one foot. It is most likely that the high chlorophyll values were associated with detritus from the sediments and therefore are not indicative of the phytoplankton at this time. Unfortunately, there is presently no way to distinguish living from detrital chlorophyll in either fresh or marine water. This disadvantage is a major hindrance to this means of determining standing crops of phytoplankton and points out a needed area of research.

Nutrients Limiting Phytoplankton Growth. One of the factors restricting fertility of the Waccasassa has been an apparent nutrient imbalance between nitrogen and phosphorus. In order to more clearly define any nutrient deficiency, estuary water was bioassayed to determine the absence of algal growth stimulating substances and to characterize these materials as far as possible. The results of one bioassay is representative of the others and is given in Table G-5. In this particular experiment a complete medium addition includes all the substances listed in Table G-1.

The bioassay indicated a shortage of available nitrogen and phosphorus. Natural phytoplankton populations were especially stimulated when nitrate was added to the environment and somewhat less by phosphorus. When these compounds were removed, photosynthesis as measured by C-14 fixation was reduced dramatically. Generally, nitrate was limiting algal growth during most of the study period except during late summer and fall. Values below 1.0 indicate a water deficient in nitrate for maximum photosynthesis. Estuarine water is nitrate poor during most of the year. This condition is especially critical from January to June and gradually improves during the last half of the year. A summary of results regarding nitrogen, as well as phosphorus, is contained in Table G-6.

Supplies of available phosphorus are inadequate for maximum productivity during certain portions of the year, usually when nitrate is in greatest demand by microorganisms. Figure G-4 shows that both of these substances may act synergistically in limiting photosynthesis. Chemical analysis indicates that total phosphorus (PO_4-P) is highest in the lower part of the estuary and averages 0.082 mg/l compared to 0.062 mg/l for the upper part. The organic fraction amounts to 73 per cent of the total either as soluble or particulate phosphorus. Nitrate levels are not distinct between the upper and lower parts of the estuary. Average NO_3-N levels at lower estuary stations were 0.034 mg/l. This was not significantly greater than the 0.029 mg/l observed in the river. Neither nitrate nor phosphorus formed a vertical concentration gradient because of the shallow depth.

Factors Affecting Primary Production. Physical, chemical, and biological factors affecting the primary productivity in the Waccasassa Estuary were determined by using stepwise multiple regression. In this program, productivity, the dependent variable, is examined with a set of possibly related independent variables. These were streamflow, sunlight intensity, chlorophyll *a*, chlorophyll *c*, primary productivity at Station 8, and temperature. Evaluations of this kind were made for each station in the estuary. In addition, integral photosynthesis for the estuary was related to bioassay for nitrate, streamflow, sunlight intensity, chlorophyll *a*, chlorophyll *c*, primary productivity at Station 5, and temperature.

An inspection of the data shows that as integral photosynthesis increases, demand for NO_3-N becomes a maximum ($r = -0.528$) and, therefore, limitations in available nitrogen will be more acute during the warm seasons than during the colder months. Since integral photosynthesis shows a positive correlation with temperature, maximum production of organic matter occurs during the summer. Although nitrogen limits plankton growth most of the year, it becomes a very critical limiting factor during the warm season; lessens as it turns cold.

Chlorophyll *a*, an indicator of the standing crop, did not show a significant correlation with integral photosynthesis. Similar results have been documented by Saunders *et al.* (17) and Goldman and Carter (18) for large fresh water lakes. However, at the upper reach of the Waccasassa Estuary and the Gulf of Mexico respectively, chlorophyll *a* was related to productivity in surface water. During the study these two areas were always lowest in productivity, which may have had some significance in the relationship to chlorophyll *a* levels.

The primary productivity was not affected by runoff from rainfall within the drainage area. The land apparently is infertile, and following heavy rains, nutrients leach out of the soil in insufficient amounts to alter productivity in any immediate way in the estuary. However, future and extensive recreational or agricultural development of the area likely will change this situation as nutrient additions would increase with these activities.

A positive correlation was noted between bioassay results and streamflow, indicating that some nitrogen and phosphorus entered the estuary from runoff. Inasmuch as the phytoplankton population was reduced during high flows, integral photosynthesis expectedly would not

Table G-6

BIOASSAY OF WACCASASSA ESTUARY
SUMMARY RELATING TO NITROGEN AND PHOSPHORUS[1]

Date	(F) NO_3-N	(F) PO_4-P
1/29/64	0.72	0.28
3/4/64	0.44	0.12
3/17/64	0.10	0.11
3/23/65	0.47	0.15
4/6/65	0.75	0.61
4/8/64	0.32	0.05
5/5/65	0.89	0.14
5/18/65	0.76	0.17
5/27/64	0.74	0.29
6/2/65	0.74	0.14
6/14/65	1.05	1.00
6/15/65	1.09	0.68
6/29/64	0.76	0.52
7/3/65	1.01	0.18
7/13/65	0.53	0.10
7/27/65	1.53	0.61
8/4/65	1.06	1.12
8/16/65	0.37	0.94
8/30/65	0.58	0.09
9/3/64	0.42	0.48
9/15/65	--	0.31
9/17/64	1.48	1.63
9/24/65	1.32	1.07

Values <1.0 indicate deficiency.

Results reported as ratio of cpm $<NO_3$/complete medium and $<PO_4$/complete medium.

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[1] The ratios tabulated above are determined as the amount of $Na_2C^{14}O_3$ incorporated by phytoplankton in a medium deficient in nitrate or phosphorus as compared to a medium complete with all necessary growth substances. Thus:

$$F \text{ (factor)} = \frac{\text{counts per minute of culture } <NO_3\text{-N or } <PO_4\text{-P}}{\text{counts per minute of culture in complete medium}}$$

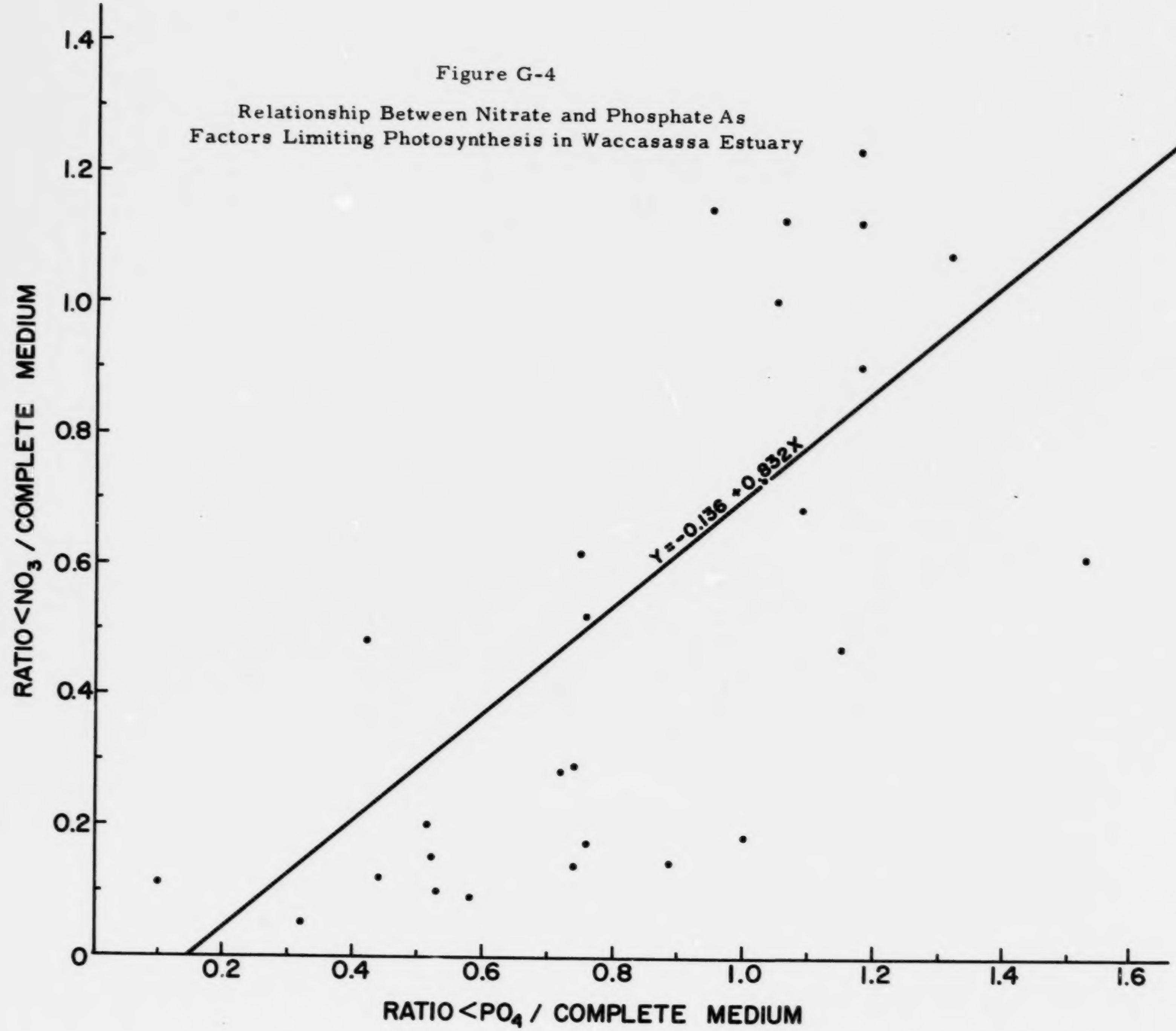

Figure G-4

Relationship Between Nitrate and Phosphate As Factors Limiting Photosynthesis in Waccasassa Estuary increase even when nitrogen and phosphorus were immediately available.

Sunlight attenuation in subsurface water is a major factor limiting integral photosynthesis in estuaries. Average extinction coefficients per meter were as high as 2.4. During this study there was always a marked drop in carbon-14 fixation in clear bottles suspended below the surface. Usually the photosynthesis of phytoplankton in bottom water would be less than 5 per cent of surface rates, but on days of high light intensity values as great as 29 per cent were recorded.

As yet the Waccasassa Estuary receives no substantial amount of human wastes, and observable cultural eutrophication effects are absent. Disposal of these substances is, however, almost a certainty for the future. With the growth of recreation, agriculture, and industry in the drainage basin of the Waccasassa, wastes of various kinds may be expected to increase and add nutrient salts to the estuary. Since there is good evidence that nutrients accumulate and are metabolically recycled in the system, the addition of allocthonous organic materials in large quantities must be viewed with concern.

The Waccasassa estuarine data collected thus far does not show an increasing concentration gradient of nitrogen or phosphorus with depth. Bottom water incubated at the surface in productivity experiments was no more fertile than surface water, and significant salinity gradients in the day did not develop except at times of very high flows from the Waccasassa River. The shallow depth of the lower estuary is a principal factor against the establishment of a persistent two-layer flow which might enhance its productivity. However, the embayment as a whole is the most productive of the estuary, and it seems justifiable to assume that the few fertilizing elements carried by the river are biologically removed before the water reaches the Gulf of Mexico. This effect is enhanced during low river flow when the residence time is as long as 4.4 days.*

The productivity of phytoplankton at the present time appears in part to be regulated by available nitrogen and phosphorus. These substances are in greatest demand when photosynthesis is at a maximum. These events usually occur during the warm seasons. Phytoplankton production in the estuary was not influenced by runoff from rain since there was no statistical relationship between streamflow and amount of photosynthesis. The soils are sandy, and annual precipitation in excess of 50 inches (127 cm) continually leaches out the few available nutrients.

The phytoplankton community is dominated by diatoms during the entire year, and these forms likely contribute a major portion of the organic production of suspended algae. Certainly the phytoplankton can serve as important indicators of environmental conditions, and species changes within the community structure may be anticipated during cultural eutrophication effects.

As yet no estimate is available with regard to the total productivity of the Waccasassa Estuary. The emergent marsh grasses, *Spartina* and *Juncus*, large attached algae and spermatophytes, and the microflora of the intertidal banks all contribute significant quantities to the annual crop of organic matter. The production by phytoplankton in the Waccasassa Estuary system amounts to only a small portion of the total.

Summary

Primary productivity in the Waccasassa Estuary is highest during June (761 mg C/m^2/day). Vernal and autumnal growth pulses of the phytoplankton were detected within the estuary as reflected by carbon-14 fixation rates.

Productivity increased from the upper reaches of the estuary to the embayment. Nutrients contained in water from the Waccasassa Estuary from Stations 1-6 are biologically removed as it passes through the embayment to the Gulf of Mexico. A residence time in the bay of 4.4 days allows adequate time for available nutrients to be utilized by phytoplankton.

The estuary has a shortage of nitrogen and phosphorous for maximum photosynthesis, and algal growth is especially limited by these substances. Organic wastes placed in the system presumably would increase the productivity of the estuary. However, the value of crop increase of edible marine organisms by organic enrichment of the water may be overshadowed by health hazards involved, especially from enteric viruses and bacteria concentrated by shellfish. Therefore the introduction of domestic sewage into this estuary should be made with caution.

The standing crop of phytoplankton is composed mainly of diatoms. These organisms are most abundant at all seasons of the year. Plant pigment analyses showed average values distributed as follows: chlorophyll *a*, 11.95 mg/m^3; chlorophyll *b*, 4.05 mg/m^3; and chlorophyll *c*, 14.27 mspu/m^3.

H. SANITARY SURVEY

Human Wastes

No sewered towns are located within the Waccasassa surface drainage basin. Under conditions of persistent and strong westerly winds it is possible that traces of pollution from Cedar Key could be found in Waccasassa Bay.

The village of Otter Creek has a total population of

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*See under K. DIFFUSION AND POLLUTION ASSIMILATION for discussion of flushing time.

399. This is served by 50 septic tanks, 25 pit privies, and 25 open privies. The septic tanks and pit privies are located a minimum of 50-100 feet from any surface drainage. Twenty per cent of the open privies are located on the banks of Otter Creek on the north side of town, and most of the remainder are located in the southwest part of town which drains into the creek. The local pollution problem is acute during periods of extremely high water, at which time one or more of the septic tanks may cease to function, and wastes from the open privies are washed into the surface drainage. A less acute problem exists during periods of extremely dry weather, when wastes from the pit privies can find their way into the expanded zones of the shallow wells in the area.

Gulf Hammock community includes scattered dwellings from two to five miles along highways on each side of the town of Gulf Hammock. The total population of the community is 238. The town itself is a source of minor pollution. This area contains 25 open privies whose wastes can reach the Wekiva during periods of above normal rainfall.

There are quite a number of residences and hunting and fishing lodges (including Camp Wekiva) located in the general Gulf Hammock area. Most of these are equipped with septic tanks, the effluents from which do not contaminate the Wekiva River except under extreme conditions of flooding. There are a few open privies which produce similar occasional pollution.

In the Cow-Ten Mile Creek area there are a number of hunting shacks which are occupied periodically from November to January. Some have open privies; some do not. These are a source of pollution.

Williams Fish Camp at Station 1 near the head of the estuary comprises a number of buildings, some of which drain to a makeshift septic tank, and some of which have open privies. All of these contribute occasional pollution to the estuary from human sources.

Animal and Industrial Wastes

The fecal coliforms which were found at sampling stations along the Waccasassa system are due chiefly to animal excrement. There are some 300 head of cattle, 100 head of hogs, a pony farm, a chicken ranch, and an unknown number of wild hogs on the Upper Waccasassa and its tributaries. Wastes from the chicken ranch are collected and removed so that they contribute only occasional pollution.

There are no industrial wastes reaching the surface waters of the Waccasassa system.

Conclusions

Inspection of the results of sampling for total and fecal coliforms discussed in Section I (see Figures I-5 and I-6) indicate moderate pollution in the headwater streams which is reduced to minor proportions in the lower estuary. Samples collected in 1963 in connection with official shellfish pollution monitoring indicate an M.P.N. of 3 per 10 ml in Waccasassa Bay.

I. PHYSICAL, CHEMICAL, AND BACTERIOLOGICAL ANALYSES

The Program

Sampling stations were established on the Waccasassa River and Estuary located so as to reflect the effects of tributary streams and to record conditions in both fresh water and saline water sections. Locations of these sampling stations are shown in Figure A-2. Samples were collected in part weekly and in part biweekly on the same day of the week for a period of 32 weeks during 1962 and 1963. Because of exceptionally low streamflow during most of this period, additional sampling was carried out at less frequent intervals during 1964 and 1965. Samples were transported to the laboratory and bacteriological and chemical examinations were initiated within 18 hours of collection. Over 15,000 analyses were made in the course of the Waccasassa study.

In addition to the routine sampling program referred to above, extended sampling surveys were carried out at appropriate times throughout the study period in order to examine the effects of tidal stage and depth upon chemical characteristics of the estuary. The findings from these studies are discussed under J. CHEMICAL CHARACTERISTICS.

Except for extended sampling studies, the samples were collected as nearly as possible to the center of the stream and approximately one foot below the surface. Where depth was appreciable, an additional sample was taken at one foot above the bottom. While efforts were made to collect samples at high or low water slack, this was not always possible. However, during the sampling period from January to October, 1963, of 325 sampling collections, 50 per cent were made within one hour of slack and 80 per cent within two hours of slack.

Certain determinations were of necessity made in the field, such as dissolved oxygen, temperature, and transparency. All of the other determinations on the samples were made in the laboratory, the samples being returned the same day for chemical and bacteriological analyses.

Description of the methods of chemical and bacteriological analyses employed are given in Appendix 2 to this report and the tables of analyses are contained in Section L.* Table I-1 and I-2 are illustrative of the analyses reported in that Section.

The plan for the entire study included determinations

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*Refer to Preface for list of Section Reports.

Table I-1

PHYSICAL AND CHEMICAL RESULTS OF ROUTINE SAMPLING

Station 4

Date	Depth (ft)	Wind Direc.	Temp. °C	Color units	Turb. units	DO mg/1	5 day BOD mg/1	Sal. °/oo	Cl. mg/1	pH units	Nitrogen T.O.N. mg/1	Nitrogen NO_3 mg/1	Tot. Solids mg/1
10/23/62	13	W2	24	50	4.0	6.8	-	8.92	4950	7.3	0.28	<0.01	10056
11/14	1	NE2	18	25	1.5	7.2	0.6	1.83	1002	7.4	-	<0.01	2228
12/4	1	S4	15	30	2.0	7.8	0.5	9.54	5295	7.5	0.56	<0.10	1050
12/18	1	Calm	10	30	4.5	8.8	1.2	3.73	2051	7.5	0.56	<0.10	4492
1/7/63	1	NW4	12	35	3.6	8.4	1.6	11.48	6392	7.2	0.28	<0.10	14276
”	35	NW8	12	35	4.6	7.6	1.0	13.86	7727	7.6	0.28	<0.10	17276
1/14	1	NE3	15	28	2.5	6.8	1.0	2.00	1100	7.2	0.28	<0.10	2372
”	31	NE3	15	35	3.0	6.7	1.5	11.14	6200	7.1	0.28	<0.10	13712
1/22	1	NW5	18	35	1.2	6.8	0.7	4.45	2450	7.2	0.42	<0.10	5012
”	29	NW5	17	45	3.0	6.6	1.5	12.03	6700	7.3	0.28	<0.10	13388
1/28	1	NE10	12	40	5.2	7.2	0.9	1.70	950	6.9	0.28	<0.10	2136
”	14	NE10	13	45	4.2	7.5	1.8	8.56	4750	7.2	0.28	<0.10	9820
2/11	1	SW10	15	65	3.8	7.6	0.7	0.76	404	7.7	0.28	<0.01	1188
”	8	SW10	16	75	6.8	7.7	0.8	1.80	1010	7.5	0.28	<0.01	2480
2/19	1	SW10	16	45	11.2	8.8	1.0	13.31	7424	7.9	0.28	<0.01	15420
”	24	SW10	15	50	13.8	8.7	1.1	13.49	7525	8.0	0.28	<0.01	15580
2/25	1	NW7	15	80	2.4	7.9	1.0	-	116	7.6	0.56	<0.01	400
”	13	NW7	15	70	4.4	7.1	0.9	3.30	1818	7.6	0.56	<0.01	4158
3/4	1	SE5	19	100	3.2	7.4	1.2	0.76	408	7.3	0.28	<0.01	984
”	27	SE5	17	50	4.2	6.5	0.6	10.89	6070	7.3	0.28	<0.01	12652
3/11	1	SE12	20	100	4.5	7.5	0.8	0.48	252	7.5	0.70	<0.01	944
”	17	SE12	19	100	6.3	7.6	1.1	0.44	227	7.6	0.56	<0.01	984
3/18	1	W8	24	120	2.1	5.1	0.9	-	56	7.2	0.70	<0.10	600
”	22	W8	23	120	1.2	4.9	0.7	-	82	7.1	0.56	<0.10	636
3/25	1	W12	18	90	6.2	7.5	0.8	0.39	202	7.7	0.56	<0.10	896
”	14	W12	17	90	7.4	7.2	0.8	0.48	252	7.5	0.56	<0.10	924
4/1	1	NE8	22	60	4.5	7.2	1.1	3.88	2140	7.2	0.56	<0.10	4990
”	11	NE8	22	50	13.0	6.6	1.2	10.75	5980	7.3	0.98	<0.10	12520
4/8	1	W10	23	50	7.2	6.6	1.9	10.45	5810	7.5	0.42	<0.01	12176
”	17	W10	23	55	9.4	6.3	1.3	11.18	6220	7.6	0.56	<0.01	12976
4/15	1	SW12	23	45	4.4	7.0	1.3	3.68	2020	7.5	<0.10	<0.10	4288
”	18	SW12	21	55	5.0	5.3	0.9	10.89	6060	7.5	<0.10	<0.10	12612
4/22	1	SW10	26	30	10.2	5.9	2.2	12.81	7140	7.6	0.19	<0.01	14928
”	19	SW10	26	40	14.0	5.8	1.8	13.17	7340	7.8	0.22	<0.01	15728

Table I-2

RESULTS OF BACTERIOLOGICAL EXAMINATIONS

Station 4

Date Collected	Time Collected	Depth Collected (ft)	Temp. °C.	S.P.C.	Coliforms MPN/100 ml	Coliforms Fecal MPN/100 ml
3/18/63	1035	1	23.5	10000	930	230
"	1035	23	23	12000	430	91
3/25	1150	1	18	2500	930	91
"	1150	15	17	3500	930	230
4/1	1215	1	22	1800	230	<36
"	1215	12	22	410	36	91
4/8	1428	1	23	400	430	230
"	1428	18	23	300	230	36
4/15	1240	1	22.5	7500	230	<36
"	1240	19	21	420	36	<36
4/22	1310	1	23	460	430	<36
"	1310	20	25.5	900	91	<36
4/29	1315	1	24.5	250	36	<36
"	1315	25	23	300	91	<36
5/6	0920	1	23	1200	91	-
"	0925	10	23.5	350	36	-
5/13	1645	1	27.5	530	36	-
"	1645	14	27.5	530	36	-
5/20	1440	1	29.5	750	73	<36
"	1440	18	29	950	36	<36
5/27	1410	1	28.5	200	72	36
"	1412	21	27	250	91	<36
6/3	1313	1	27	110	<36	<36
"	1313	30	27	150	<36	<36
6/11	1250	1	28	440	750	200
"	1250	26	27.5	500	73	73
6/17	1140	1	29	330	<36	<36
"	1140	21	28	400	36	<36
6/24	1125	1	29	510	930	36
"	1125	13	27.5	2700	930	36
7/1	1055	1	28.5	300	<36	<36
"	1055	20	28	300	36	<36
7/15	1728	1	27	9600	11000	<36
"	1728	21	28	400	930	<36
8/12	1558	1	30	12000	750	230
"	1558	27	29	370	230	23
9/3	1600	1	30	1200	91	36
"	1600	29	29	290	93	15
9/26	1307	1	-	900	2400	430
"	1307	12	-	260	150	36
10/2	1240	1	24	300	91	91
1/13/64	1140	1	12	3500	1500	230
"	1140	20	12	1700	2400	2400
1/29	1225	1	12	4000	1500	930
"	1230	23	12	2000	4600	2400
3/16	1335	1	22	1800	2300	930
"	1340	4	22.5	1200	2300	230
"	1345	7	22	1400	2300	150
"	1350	10	22.5	1400	930	430
"	1355	13	22.5	2100	9300	1500
"	1400	16	22.5	1800	930	430
"	1405	17	22.5	1600	930	430
5/25	1600	6	28	600	<36	<36
"	1050	5	27	1700	230	<36

of dissolved oxygen, turbidity, transparency, chlorides (salinity), biochemical oxygen demand, chemical oxygen demand, nitrates, phosphates,* total nitrogen, alkalinity, pH, color, and radioactivity. The test for chemical oxygen demand performed on the fresh water sections where chloride interference was not a factor indicated the amount of chemical oxygen demand to be so small that further use of this particular determination was considered unnecessary for the Waccasassa. Therefore no results have been recorded. Measurements of radioactivity were made on one series of routine samples and no radioactive pollution was indicated. Through the courtesy of Dr. H. Page Nicholson of the Southeast Water Laboratory, Federal Water Pollution Control Administration, analyses for pesticide pollution were made on samples from both the Waccasassa and Fenholloway systems. None was found and no use of pesticides was discovered in the sanitary survey. Hence no further determinations of radioactivity and pesticides were made. The other tests indicated above were made routinely on all samples collected from the sampling stations. A few determinations of sulfates were added at a late stage in the sampling program.

General Pattern of Chemical Results

The over-all results of the routine and extended sampling for chemical analysis of the waters of the Waccasassa River, Estuary, and Bay confirm the general impression, derived from the sanitary survey and from consideration of the culture of the drainage area, that these waters for the most part are free from any serious organic pollution. General results for some of the important chemical parameters are considered in turn. While the comments are based largely upon the sampling during the low flow period extending from late 1962 through 1963, check sampling during higher flows in 1964 and 1965 did not alter the general conclusions described herein.

Dissolved Oxygen. The dissolved oxygen data (Figure I-1) indicate that no substantial organic pollution enters the Waccasassa system. Higher DO at low tide than at high tide at Stations 1 and 2 is due to the influence of fresh water flow at low tide, as discussed subsequently in J. CHEMICAL CHARACTERISTICS. Some intermittent local pollution was detected by bacteriological analyses.

As the water moves down the river into the shallow bay region, reaeration is accelerated by the wave action of the bay. It has been observed that on windy days the bay approaches a dissolved oxygen concentration that approximates the theoretical saturation point. At no time during the low flows of 1963 was an appreciable oxygen sag observed, which again confirms the absence of organic pollution.

Biochemical Oxygen Demand. The biochemical oxygen demand of the entire Waccasassa system is what may be expected in a nonpolluted water, as seen in Figure I-2. Average values range from 0.96 mg/1 to 1.8 mg/1 in the system where the lower value is at Station 102 at high tide. At Station 2 some difference exists in biochemical oxygen demand at high tide and low tide for reasons explained later in the discussion of bacteriological analyses.

Chlorides. The pattern of average chloride concentrations in the estuarine system as shown by Figure I-3 is about what would be expected. At high tides Gulf water is pushed into the upper reaches of the river and increases the salinity. During normal tidal cycles, Stations 101 and 102 do not receive saline water. Only at higher high water has the chloride content increased at these stations.

Turbidity. Turbidity presented in Figure I-4 gives an indication of the fine suspended matter brought about in part by the turbulence of the water. The water in Wekiva River originates from the spring and flows over a stream bed of coarse sand, thereby resulting in a water of extremely low turbidity at Station 102. During a few of the high tide cycles, some turbidity was apparently forced upstream to this location.

From Station 101 to below Stafford Island (Figure C-1) the turbidity ranges from about 2.3 up to 8.5 units. This turbidity is the result of normal tidal flow over the rock and mud bottom of the river. In the shallow lower estuary area from Station 6 to Station 10, wind and wave action stirs up the thin layer of silt and increases the turbidity. At high tide the turbidity from the shallow flats is carried up into the river.

Nitrogen. Total organic nitrogen represents all of the nitrogen present in the reduced state. In this estuary which is unpolluted and almost saturated with oxygen, practically no free ammonia exists. Nitrates are consistently low.

Color. Runoff waters such as those found in the upper reaches of the Waccasassa River and Otter Creek have all shown color as a result of their passage through deciduous forests. In contrast to these two streams, the Wekiva River and its tributary, Mule Creek, are fed from springs and contain practically no color. From Station 1 down to Station 6 additional color is derived from black muck which forms the river banks.

Alkalinity and pH. The alkalinity and pH indicate a slightly alkaline water as would be expected from the sources described in B. GEOMORPHOLOGY. As the water travels downstream, the alkalinity increases due to

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*During the later stages of the work it was concluded that the determinations of orthophosphates were not meaningful; hence they have been omitted from the tables in Section L. Subsequent to January, 1964, total phosphate is recorded.

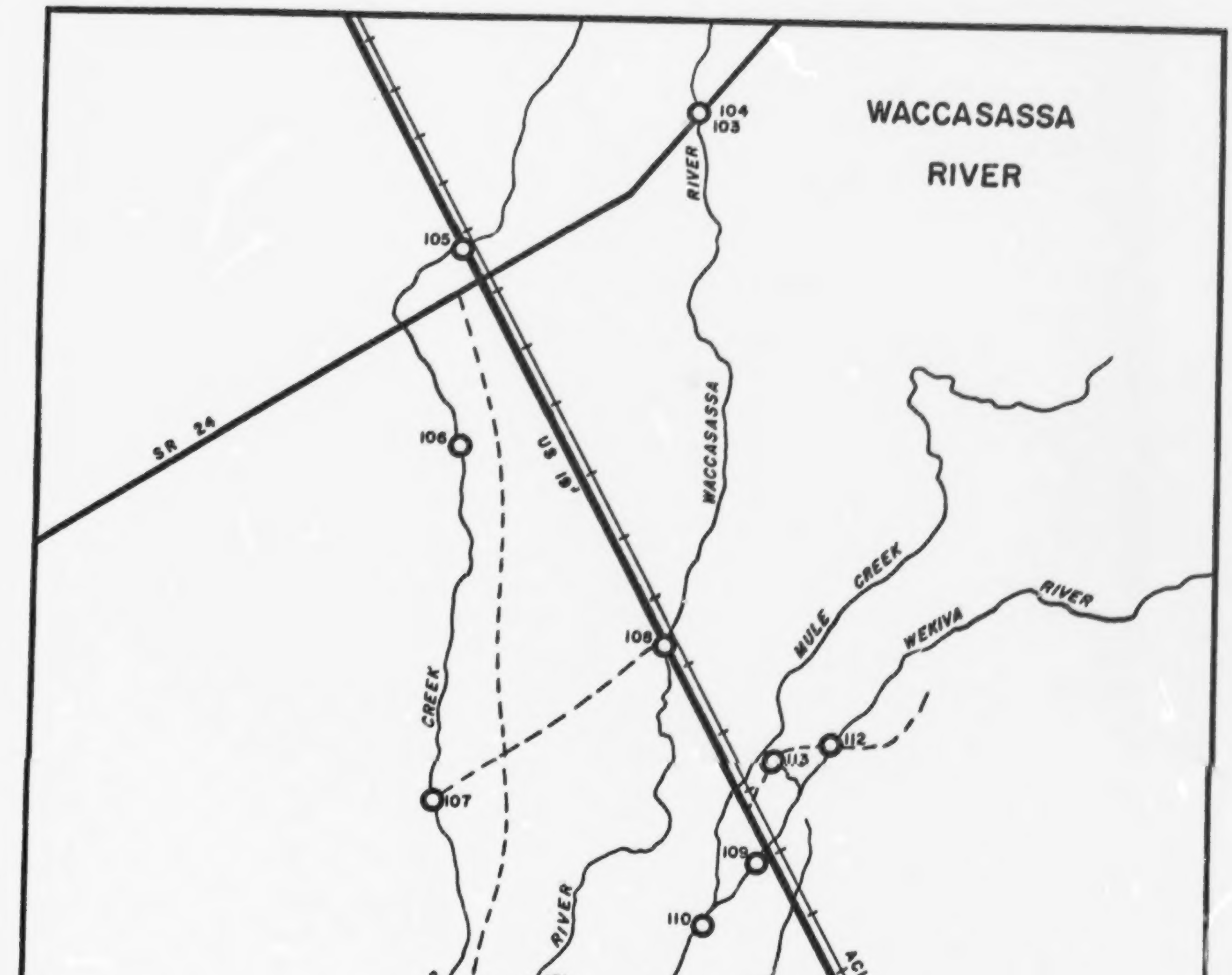
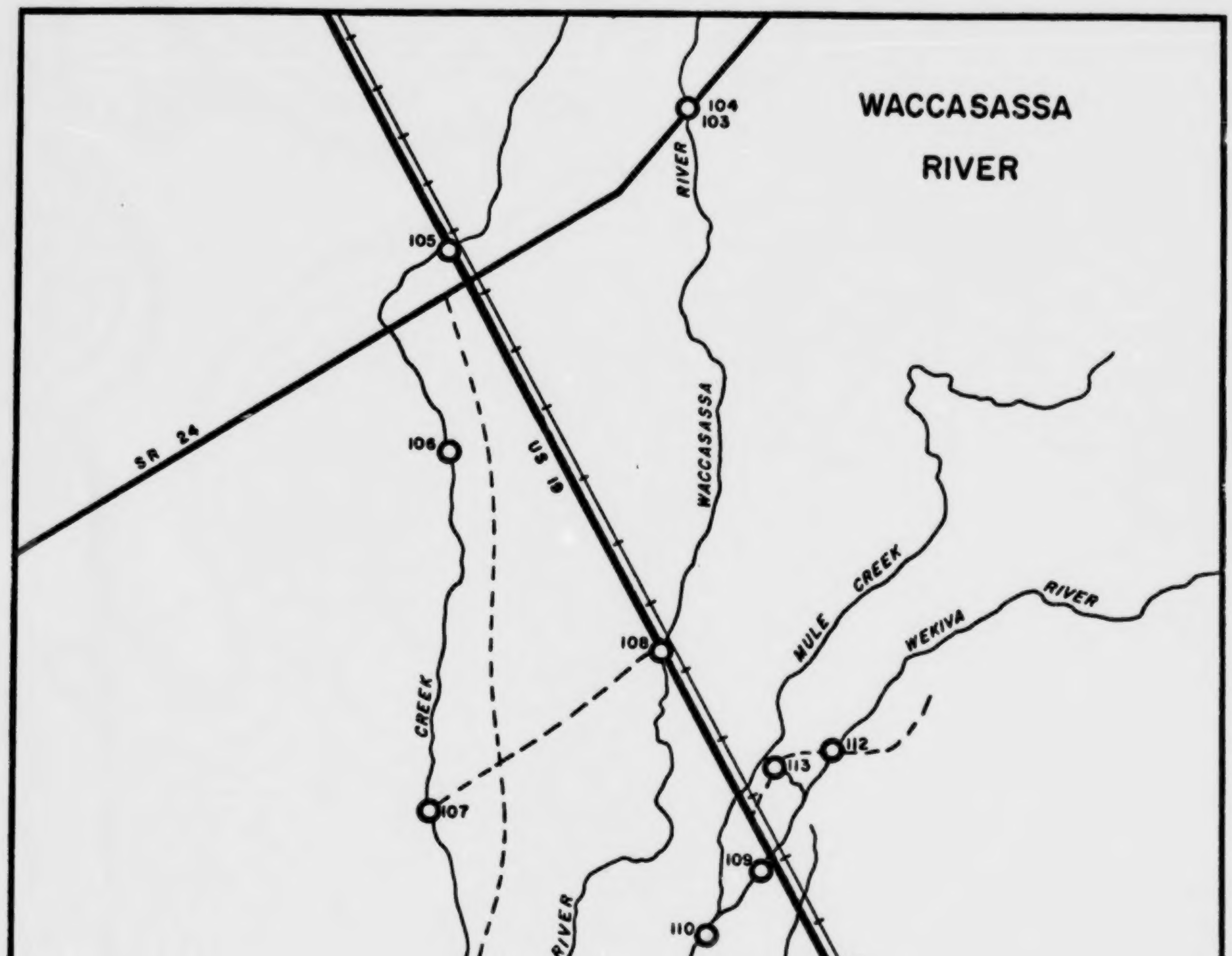

WACCASASSA
RIVER
SR 24
US 19
WACCASASSA
RIVER
MULE CREEK
WEKIVA RIVER
CREEK
OTTER
RIVER
ACL
WACCASASSA
COW
CREEK
TEN MILE CREEK
104
103
105
106
108
107
113
112
109
110
101
102
111
1
2
3
4
5
6
7
8
9
10
7.4
6.9
8.3
11.0
6.8
7.7
6.2
6.3
6.4
7.1
(6.4)
(5.1)
6.7
6.5
6.1
5.9
6.8
6.3
(6.5)
(5.6)
7.0
6.9
6.8
7.0
6.8
6.7
7.0
6.7
WACCASASSA
BAY
DISSOLVED OXYGEN - mg/l
MEDIAN VALUE
SCALE
0
1
2
3
MILES
LEGEND
HIGH TIDE
LOW TIDE
( ) BOTTOM SAMPLES

Figure I-1


BIOCHEMICAL OXYGEN DEMAND - mg/l
MEDIAN VALUES

WACCASASSA
RIVER
SR 24
US 19
ACL
WACCASASSA
RIVER
MULE CREEK
WEKIVA RIVER
OTTER CREEK
RIVER
COW CREEK
TEN MILE CREEK
WACCASASSA
BAY
103
104
105
106
107
108
109
110
111
112
113
101
1.1
1.3
102
0.90
1.1
1
1.0
0.95
2
1.5
0.95
3
1.0
1.0
4
1.7
1.1
5
1.4
1.4
6
1.6
1.4
7
1.7
1.5
8
1.6
1.5
9
1.5
1.8
10
1.4
1.5
LEGEND
HIGH TIDE
LOW TIDE
BOTTOM SAMPLES
SCALE
0
1
2
3
MILES

Figure I-2

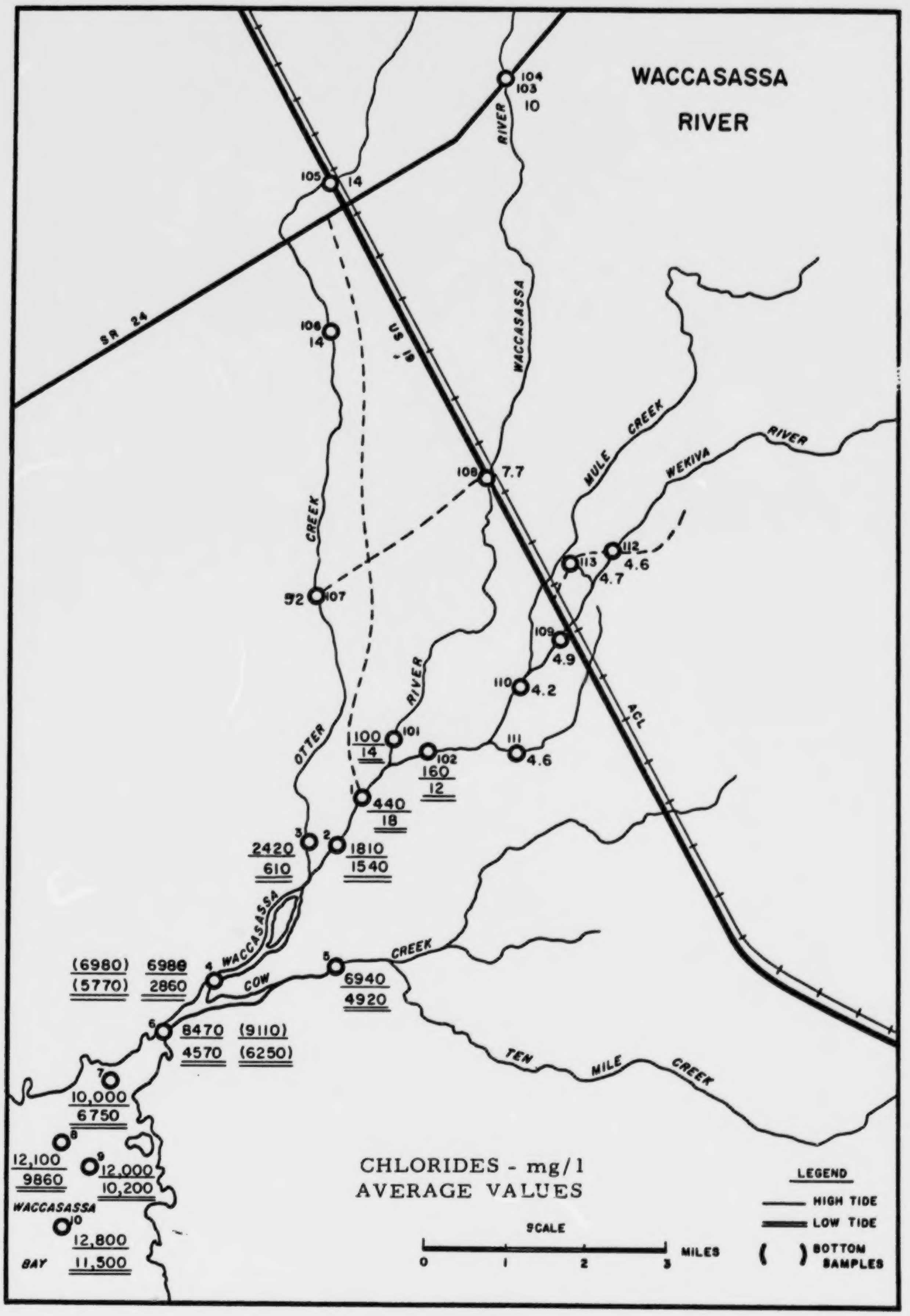

WACCASASSA
RIVER
104
103
10
105
14
SR 24
US 19
106
14
WACCASASSA
RIVER
MILE
CREEK
WEKIVA
RIVER
108
7.7
CREEK
112
4.6
113
4.7
52
107
109
4.9
110
4.2
RIVER
OTTER
100
14
101
102
160
12
111
4.6
ACL
1
440
18
3
2420
610
2
1810
1540
WACCASSASSA
(6980)
(5770)
6980
2860
4
COW
5
6940
4920
CREEK
6
8470
4570
(9110)
(6250)
TEN
MILE
CREEK
7
10,000
6750
8
12,100
9860
9
12,000
10,200
WACCASASSA
10
12,800
11,500
BAY
CHLORIDES - mg/l
AVERAGE VALUES
LEGEND
HIGH TIDE
LOW TIDE
( ) BOTTOM SAMPLES
SCALE
0
1
2
3
MILES

Figure I-3

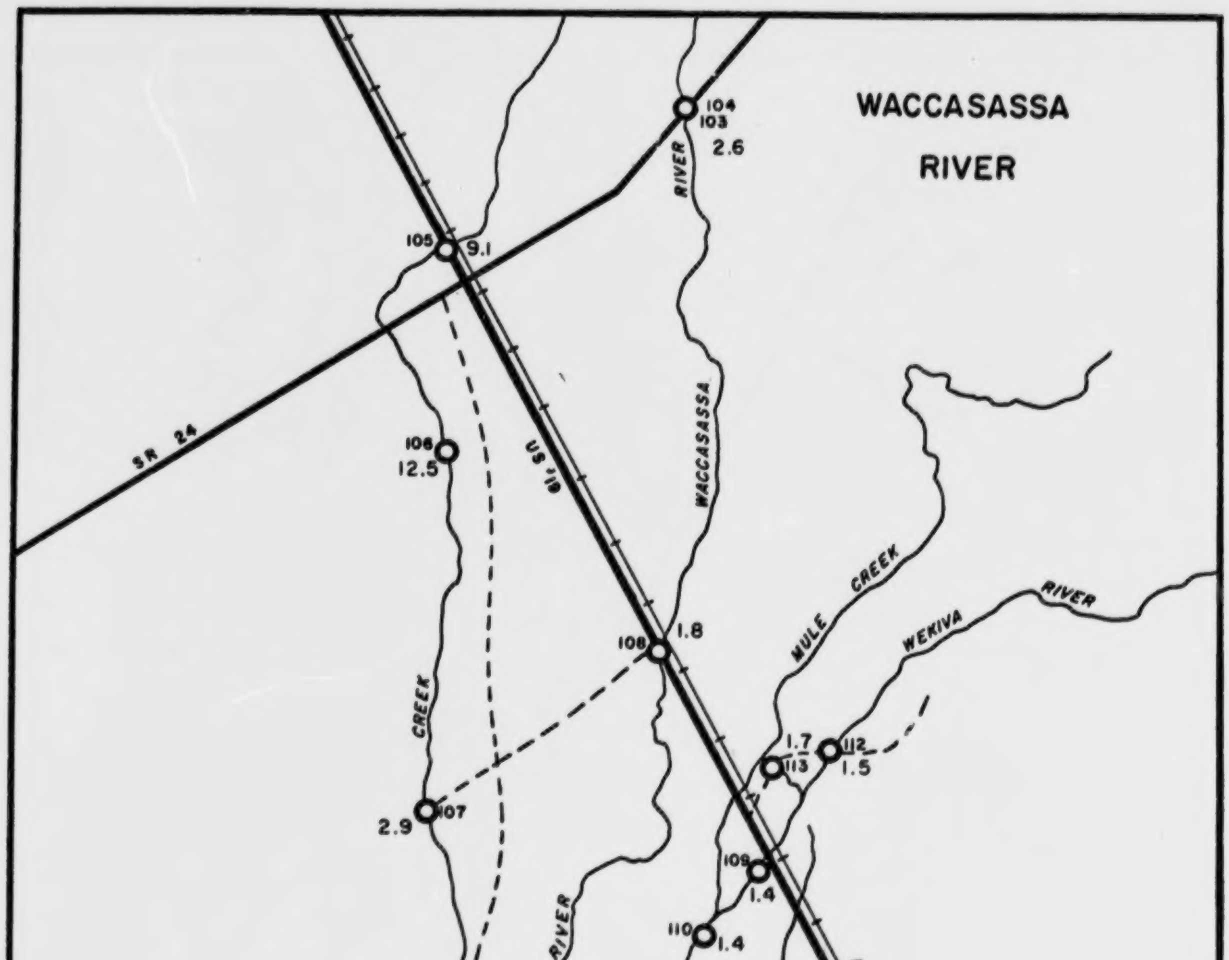

WACCASASSA
RIVER
SR 24
US 19
ACL
WACCASASSA RIVER
OTTER CREEK
RIVER
MULE CREEK
WEKIVA RIVER
WACCASASSA
COW CREEK
TEN MILE CREEK
WACCASASSA BAY
104
103
2.6
105
9.1
106
12.5
108
1.8
107
2.9
1.7
113
112
1.5
109
1.4
110
1.4
111
101
8.5
2.5
102
4.4
1.9
1
3.8
2.3
3
4.8
3.1
2
4.6
2.5
4
(15.5)
(6.3)
12.1
4.4
5
19.5
5.4
6
15.5
4.9
(16.3)
(7.3)
7
16.6
7.3
8
16.4
9.8
9
14.6
11.6
10
18.4
8.3
TURBIDITY - UNITS
AVERAGE VALUES
LEGEND
HIGH TIDE
LOW TIDE
( ) BOTTOM SAMPLES
SCALE
0
1
2
3
MILES

Figure I-4

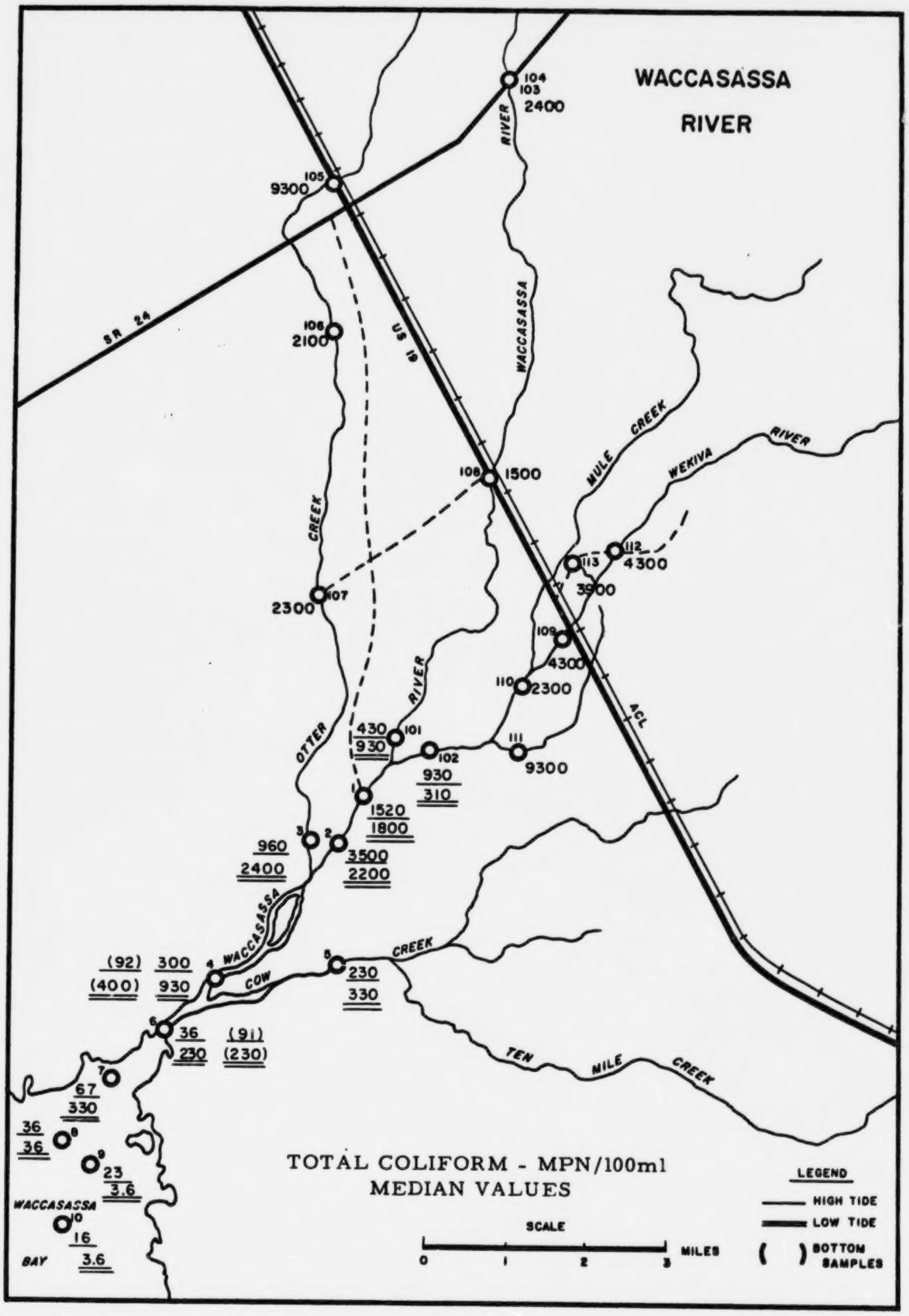

WACCASASSA
RIVER
104
103
2400
105
9300
106
2100
108
1500
107
2300
112
4300
113
3900
109
4300
110
2300
111
9300
101
430
930
102
930
310
1520
1800
3
960
2400
2
3500
2200
4
(92)
(400)
300
930
5
230
330
6
36
230
(91)
(230)
7
67
330
8
36
36
9
23
3.6
10
16
3.6
SR 24
US 19
ACL
RIVER
WACCASASSA
MULE CREEK
WEKIVA RIVER
CREEK
OTTER
RIVER
WACCASASSA
COW
CREEK
TEN MILE CREEK
WACCASASSA
BAY
TOTAL COLIFORM - MPN/100ml
MEDIAN VALUES
SCALE
0
1
2
3
MILES
LEGEND
HIGH TIDE
LOW TIDE
( ) BOTTOM SAMPLES

Figure I-5

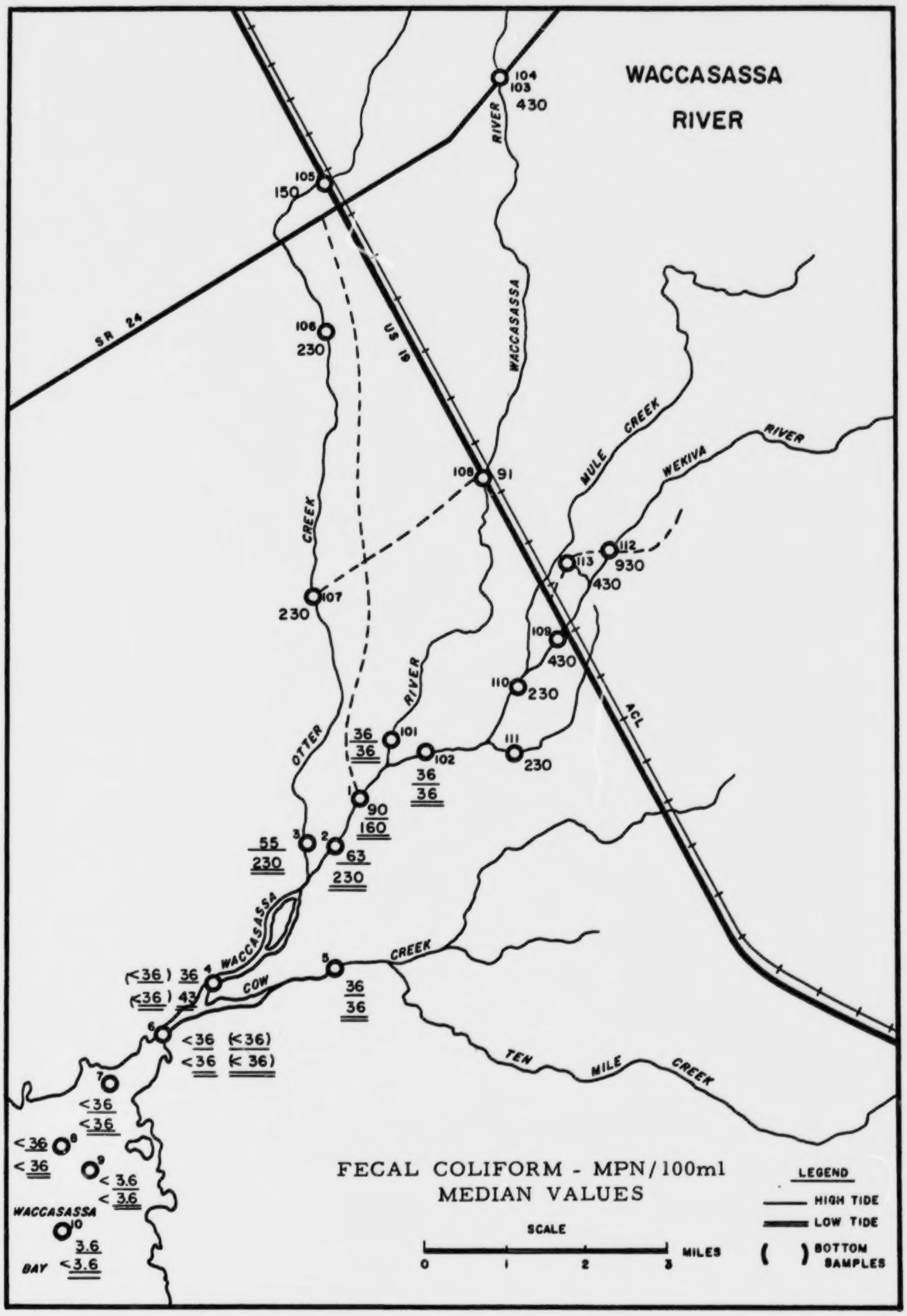

WACCASASSA RIVER
FECAL COLIFORM - MPN/100ml
MEDIAN VALUES
LEGEND
HIGH TIDE
LOW TIDE
( ) BOTTOM SAMPLES
SCALE
0 1 2 3 MILES
SR 24
US 19
ACL
WACCASASSA RIVER
OTTER CREEK
MULE CREEK
WEKIVA RIVER
COW CREEK
TEN MILE CREEK
WACCASASSA BAY
104 103 430
105 150
106 230
107 230
108 91
109 430
110 230
111 230
112 930
113 430
101 36 36
102 36 36
1 90 160
2 63 230
3 55 230
4 (<36) 36 (<36) 43
5 36 36
6 <36 (<36) <36 (<36)
7 <36 <36
8 <36 <36
9 <3.6 <3.6
10 3.6 <3.6

Figure I-6

admixture of salt water with the fresh water.

Bacteriological Examinations

Inspection of Figure I-5 will show that the median M.P.N. values for the total coliform group are significantly low, indicating that the degree of pollution of the stream is limited. The data given do indicate that in the main stream and its major tributaries above Station 1 a small amount of bacterial pollution is present. The possible sources of this pollution are recorded under H. SANITARY SURVEY.

The coliform index is slightly higher at Station 2 than at Station 1. This is probably due to the discharge from Otter Creek being carried upstream to Station 2 and beyond by flooding tides. Coliform group indexes decrease gulfward, particularly in the section of high salinity. Only minimum values are found in the lower estuary area. The natural die-away rate of coliforms in saline water plus dilution account for this.

In Figure I-6 the median M.P.N. values for the fecal section of the coliform group are shown. These are much lower than the values for the entire group. It can be concluded, therefore, that the major part of the bacterial pollution in the stream is due to stream runoff and surface drainage from the surrounding swamps and other terrain. It is probable that the organisms of the fecal section of the coliform group found originate in large measure from animal discharges. It is significant that at Station 2 the proportion of bacteria of the fecal section to the total coliform group is higher than at other sampling stations, particularly Station 1.

In general, the data resulting from the bacteriological examinations correlate well with the chemical analyses, indicating that the river is only slightly polluted and that the minor pollution disappears with diffusion into the salt water areas. The majority of the results reported were obtained during the warmer season of the year and with water temperature approximately 25°C. Streamflows were below average since rainfall during this period was limited, as indicated under D. HYDROLOGY.

During the later part of the study when air and water temperatures were lower, marked increase in the flow in the fresh water section occurred. A limited number of samples were collected during this period. The high runoff increased somewhat the degree of bacterial pollution but did not alter the conclusions reported above.

J. CHEMICAL CHARACTERISTICS

Introduction

The methods of chemical analysis are described in Appendix 2 to this report, and the general significance of the results obtained are summarized under I. PHYSICAL, CHEMICAL, AND BACTERIOLOGICAL ANALYSES. The following discussion is restricted to the results obtained for the following properties: chloride, dissolved oxygen, phosphate, nitrate, and biochemical oxygen demand. Particular emphasis is given to the data obtained in four extended sampling studies made at four different stations in the estuary because these data, together with additional extended sampling data for salinity only, permit some conclusions to be drawn concerning the circulation patterns in the Waccasassa Estuary. The discussion is based primarily upon the data obtained during 1963, a time when the fresh water flow of the Waccasassa was remarkably low and relatively constant. Dramatic changes in the longitudinal and vertical profiles of salinity were observed during periods of high fresh water flow in 1964 as indicated in Table J-1. This emphasizes the importance of adequate knowledge and consideration of the runoff in analyzing and predicting pollution assimilation in an estuary.

Sampling Programs

The routine collection of discrete surface and/or deep samples for chemical analysis at the various stations of the sampling network has been previously described. Quality data obtained in this way usually constitute a somewhat haphazard or random array unless they have been fortuitously obtained under comparable slack conditions. In order to make such data amenable to interpretation, it is necessary to relate them to the tide-induced circulation patterns in the estuary. To this end, extended sampling collection programs were carried out at Stations 1, 2, 4, 6, and 7 (See Figure A-2). Samples were collected at frequent time intervals and at several depths. Thus at a given station as many as eighty individual samples were obtained. The measurements and analyses made generally included temperatures, chloride, dissolved oxygen, phosphate, nitrate, and transparency (Secchi disk). Salinities by salinometer were determined as a part of one of these studies, as well as in individual extended investigations of depth-tide-salinity relationships at each of the stations in the estuary.

Chloride Distributions

A number of sampling studies of the lateral variation in salinity at a given station indicated that the estuary was well-mixed laterally. The detailed data obtained in the extended sampling studies are presented in Figures J-1 to J-4.* A preliminary inspection of the extended sampling chloride data reveals that chloride concentrations are clearly dependent upon both depth and tidal stage. Chloride concentration data from each of the four

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*Stations S-1, S-2, etc on figures refer to Stations 1, 2, etc. in text and Figure A-2.

Table J-1

CHLORIDE AND SALINITY DATA
WACCASASSA ESTUARY

Station	Fresh Water Streamflow Cu. Ft./Sec.	Date	High Tide Chlorides S*	High Tide mg/1 B*	High Tide Salinity S	High Tide °/oo B	Low Tide Chlorides S	Low Tide mg/1 B	Low Tide Salinity S	Low Tide °/oo B
1	100	Average	440		0.8		18		<1	
	860	1/29/64	10	13	<1					
	2100	9/17/64	5		<1					
2	120	Average	1810		3.1		1540		2.8	
	1160	1/29/64	13	14	[illegible]					
	3540	9/17/64	6		[illegible]					
4	125	Average	6980	6980	12.5	12.5	2860	5770	5.2	10.4
	1200	1/29/64	48	70	<1					
	4000	9/17/64	7	9	<1					
6	135	Average	8470	9110	15.2	16.3	4570	6250	8.2	11.2
	1290	1/29/64	108	114	<1	<1				
	4500	9/17/64	10	10	<1	<1				
8	135	Average	12000		21.4		9860		17.6	
	1500	1/29/64	4475		8.1					
	5000	9/17/64	1050	1480	1.9	2.7				
10	135	Average	12800		22.8		11500		20.5	
	1500	1/29/64	6750		12.2					
	5000	9/17/64	1250	1850	2.3	3.4				

*S=1 ft. below surface
B=1 ft. above bottom

NOTE: High and low tide data applies only to average flow conditions. Data for high flows of 1/29 and 9/17 are in High Tide column, but observations were made during a half tidal cycle.

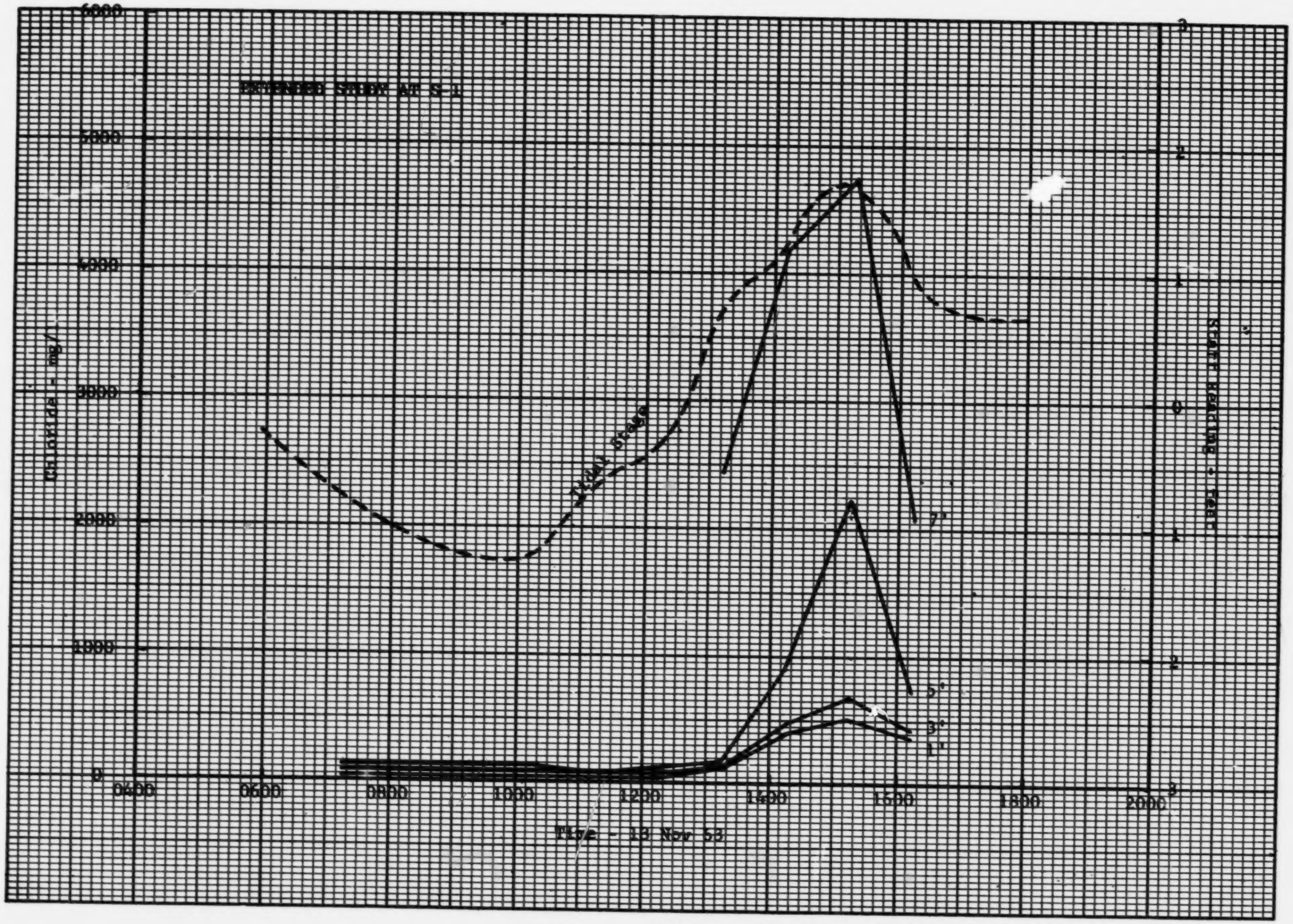

EXTENDED STUDY AT S-1
Chloride - mg/l
6000
5000
4000
3000
2000
1000
0
0400
0600
0800
1000
1200
1400
1600
1800
2000
Time - 13 Nov 53
Staff Reading - Feet
3
2
1
0
1
2
3
Tidal Stage
7'
5'
3'
1'

Figure J-1

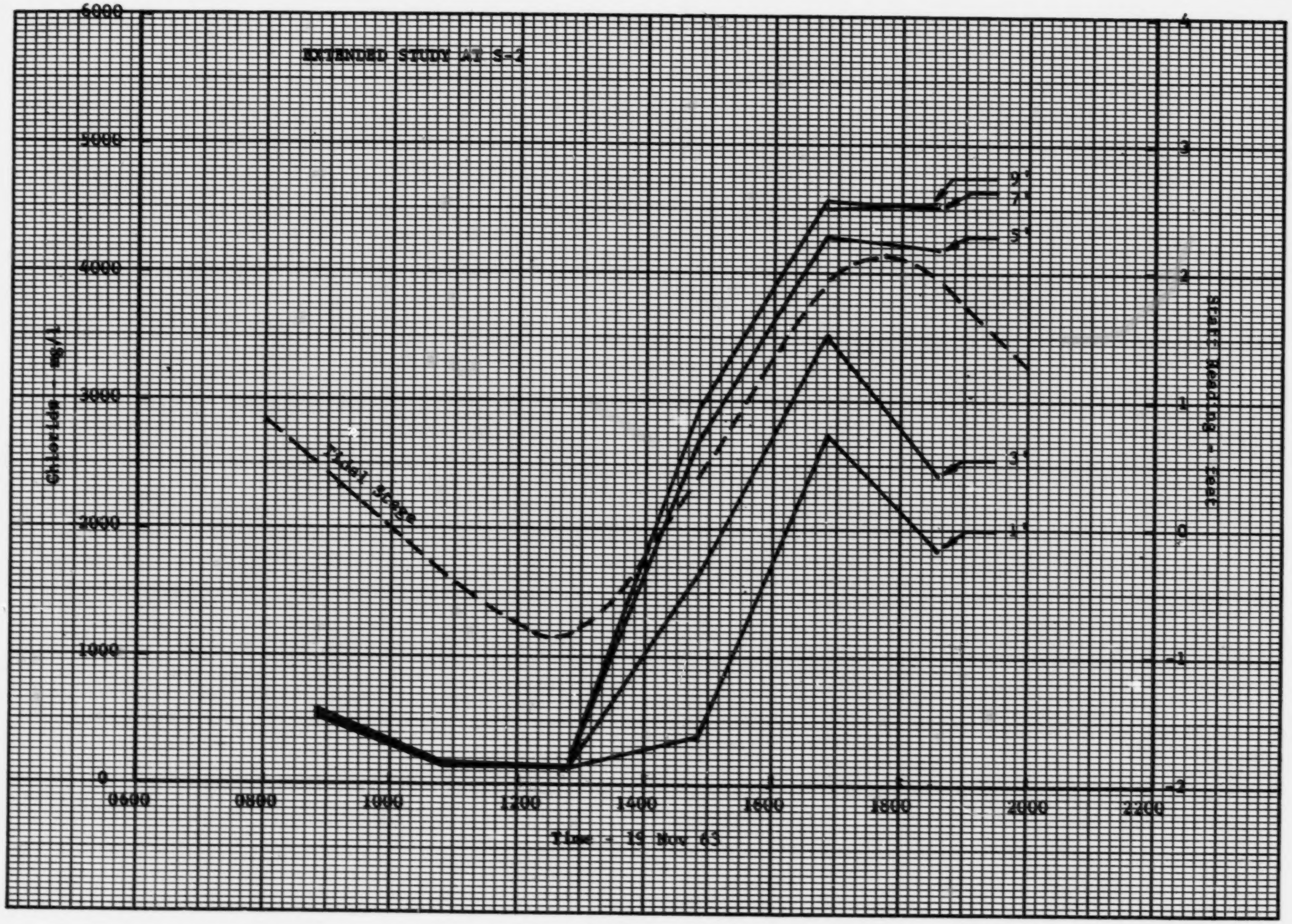

EXTENDED STUDY AT S-2
Chloride - mg/l
6000
5000
4000
3000
2000
1000
0
Staff Reading - feet
4
3
2
1
0
-1
-2
0600
0800
1000
1200
1400
1600
1800
2000
2200
Time - 19 Nov 65
Tidal Stage
9'
7'
5'
3'
1'

Figure J-2

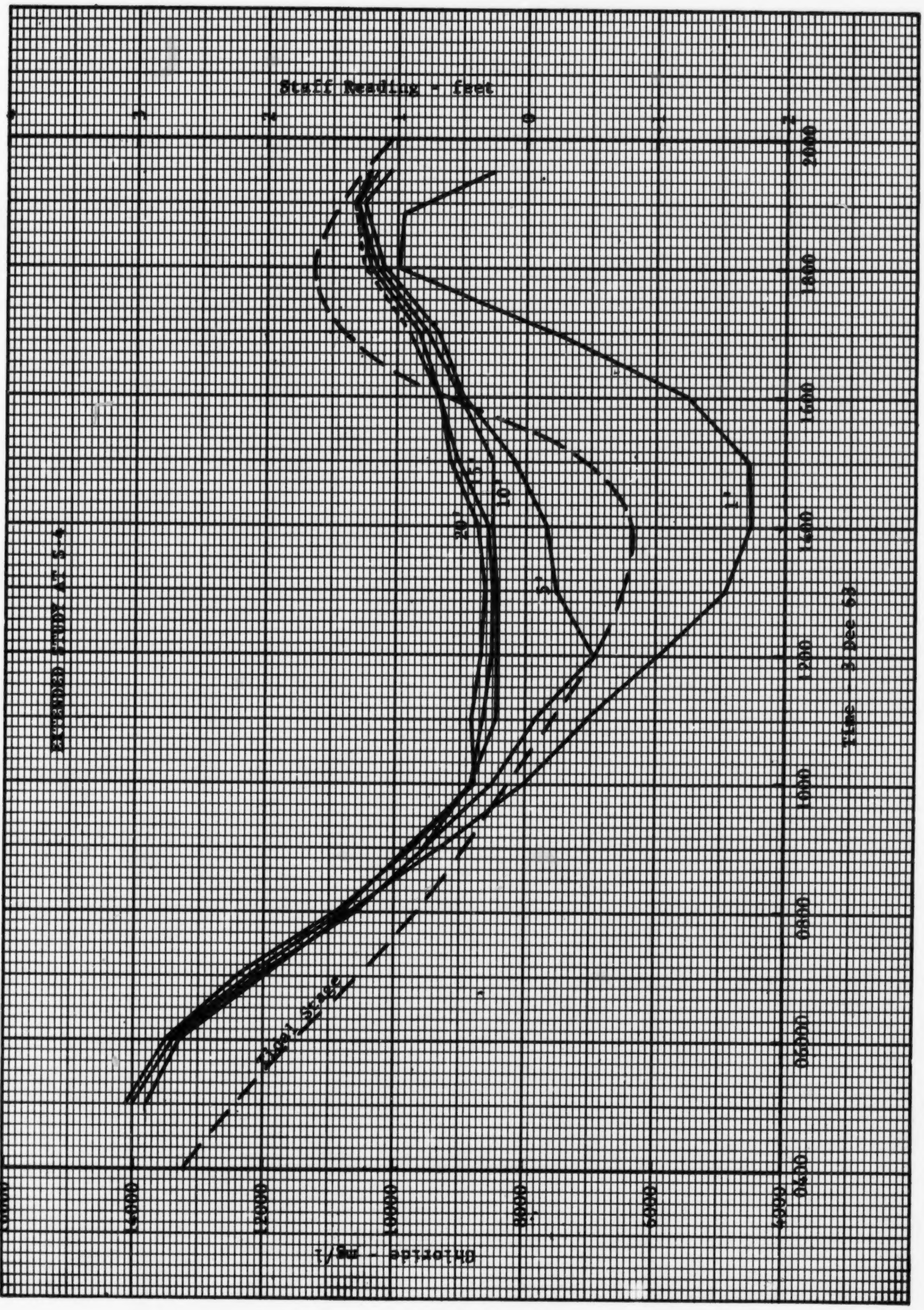

EXTENDED STUDY AT S-4
Staff Reading - feet
0
Chloride - mg/l
16000
14000
12000
10000
8000
6000
4000
Time - 3 Dec 68
0400
0600
0800
1000
1200
1400
1600
1800
2000
Tidal Stage
20'
5'
10'
2'
1'

Figure J-3

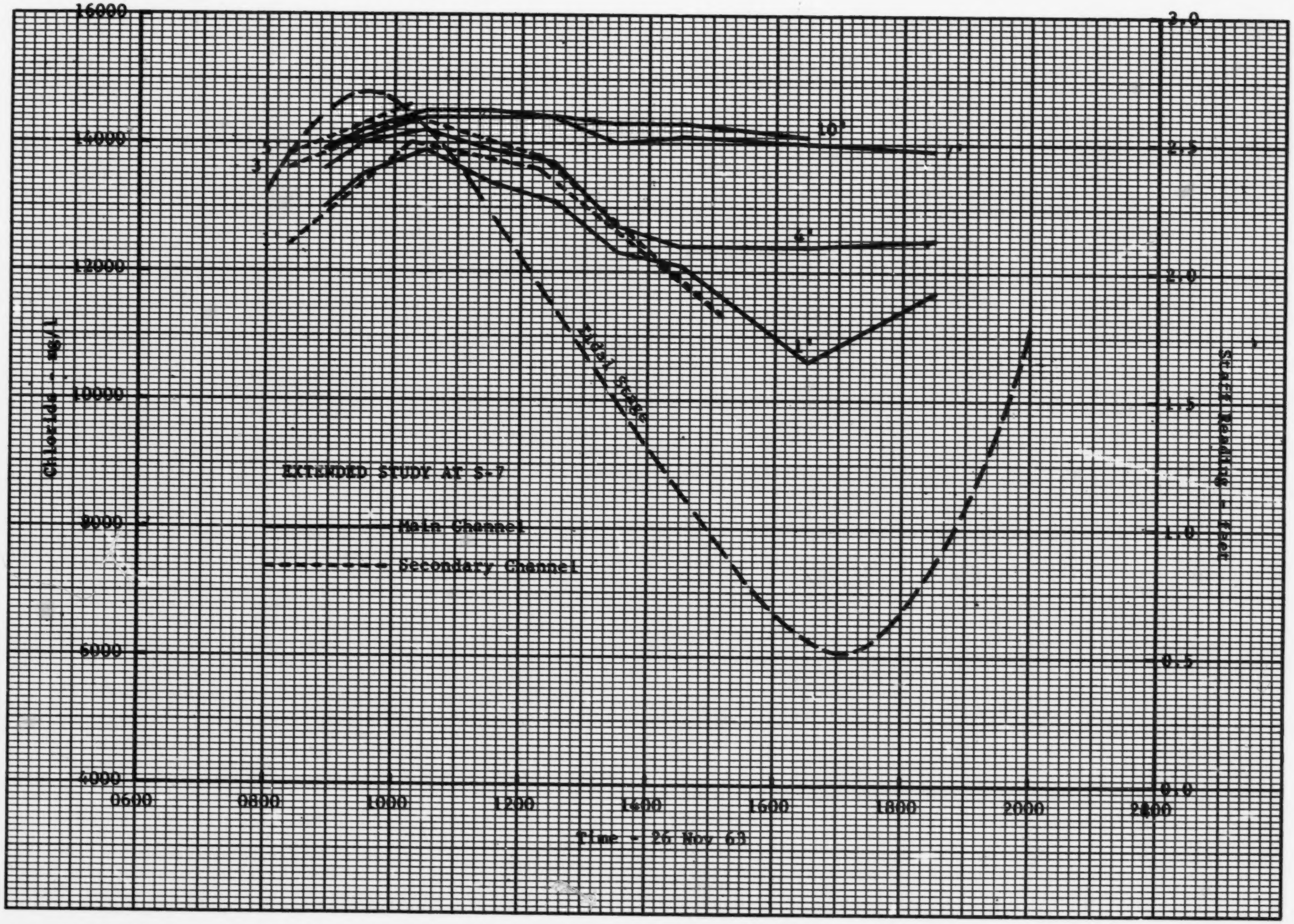

16000
14000
12000
10000
8000
6000
4000
Chloride - mg/1
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Staff Reading - Feet
0600
0800
1000
1200
1400
1600
1800
2000
2400
Time - 26 Nov 63
EXTENDED STUDY AT S-7
Main Channel
Secondary Channel
Tidal Stage
10'
7'
6'
3'
1'

Figure J-4

sampling stations involved have been averaged with respect to time and are plotted in Figure J-5. It is apparent that the estuary cannot be regarded as vertically homogeneous; it might be described as moderately stratified (1). Salinity data of a similar nature have been used to calculate temporal-spatial mean salinities for each station. These means have been employed in Section K to estimate longitudinal mixing coefficients for the estuary (3).

Some representative data for chlorides, dissolved oxygen, phosphates, and nitrates obtained at the different sampling stations are shown in Figures J-6a to J-9c inclusive. Comparison of Figures J-6a and J-9a, which present chloride concentration profiles for different slack conditions at Stations 1 (near the fresh water end of the estuary) and 7 (near the salt water end of the estuary), reveals a rather clear difference in the structure of the fresh water-salt water mixing at these locations. At the fresh water end of the estuary, mixing is most complete near low water slack, while at the salt water end, mixing is most complete near high water slack. The profiles at Station 1 suggest that salt water largely flows under fresh water at high tide, approaching to some extent a salt-wedge phenomenon (1). The salt-wedge estuary occurs when the ratio of river flow to tidal flow is relatively large and when the ratio of width to depth is relatively small. The profiles at Station 7 indicate that the turbulence of the tidal motion at high water slack is sufficient to achieve almost complete mixing, but that partial stratification occurs at low water (turbulent eddies mix salt water upward and fresh water downward, but a vertical salinity gradient remains). A comparison of Figures J-7a and J-8a with the two foregoing figures indicates that the estuarine structures at Stations 1 and 2 are similar and and that those at Stations 4 and 7 are similar. Between the stations there is thus a change in the predominant vertical structure of the estuary under the low flow conditions prevailing during the extended sampling.

On the basis of the preceding facts about chloride distributions, one can draw the following inferences. Surface sampling alone is insufficient to obtain an accurate description of the longitudinal profile of a conservative property such as chloride. While the "same slack" sampling technique at different longitudinal stations of an estuary is useful in eliminating the translatory effect of the tidal motion from observed profiles of such properties as dissolved oxygen, chloride, BOD, etc., it yields unambiguous results only if the estuary is vertically homogeneous or if the sampling program is adequate for defining vertical profiles at a given slack. For the Waccasassa, under runoff conditions similar to those which prevailed throughout most of 1963, the need for sampling at different depths is apparent.

While surface sampling at a high water slack in the lower portion of the estuary should yield concentration data representative of an approximately vertically mixed condition (compare Figures J-8a and J-9a), the same technique does not yield comparable data for the upper portion (compare Figures J-6a and J-7a). The most expedient sampling program in order to evaluate longitudinal concentration profiles of chemical and biological properties in the Waccasassa Estuary under polluted conditions and at low fresh water flow should consist of multiple depth sampling at both high and low water slack at each station of interest. Sampling of this kind, under reasonably constant and known fresh water flow conditions, is the most useful in obtaining an accurate description of estuary properties. A similar view has been expressed by Selleck and Pearson (2) and by Bowden (3).

Profiles of Oxygen, Phosphate, Nitrate, and Other Species

Reference to Figures J-6b, J-7b, J-8b, and J-9b, which show vertical dissolved oxygen profiles at representative stages of the tide for four sampling stations, indicates that the effects of tide upon both the displacement of the profiles and the vertical gradient are not at all similar to the effects observed in the case of salinities. This observation is consistent with the fact that in this rather unpolluted estuary the only properties which exhibit decided longitudinal concentration gradients are salinity (or chloride), turbidity, color, and bacterial numbers. The vertical gradients which are so evident for chloride are essentially absent for dissolved oxygen. Since d(O_2)dx is close to zero, incomplete vertical mixing of salt and fresh water, i.e., of downstream and upstream water volumes, does not lead to a very large value of d(O_2)dz. This clearly would not be the result under conditions where a pronounced longitudinal oxygen gradient exists (an oxygen "sag"). Here different vertical profiles would be anticipated for different tidal stages, as is observed for chloride. The existence of some small vertical DO gradients which can be noted in Figures J-6b to J-9b is attributable to the slight longitudinal DO gradient; the gradients could also be due, at least in part, to depth-dependent photosynthetic activity.

A limited number of extended sampling data are available for phosphate (orthophosphate plus hydrolyzable inorganic condensed phosphate). These are shown in Figures J-7c and J-9c. Some vertical gradients are evidenced, but these are perhaps due chiefly to biological processes rather than to incomplete mixing (4). A slight longitudinal gradient appears in the data from the routine weekly sampling program. Available published data on inorganic phosphate levels in Gulf of Mexico waters (5) indicate expected phosphate concentrations in the salt water of roughly 10 to 20 μg PO_4 per liter. The data from

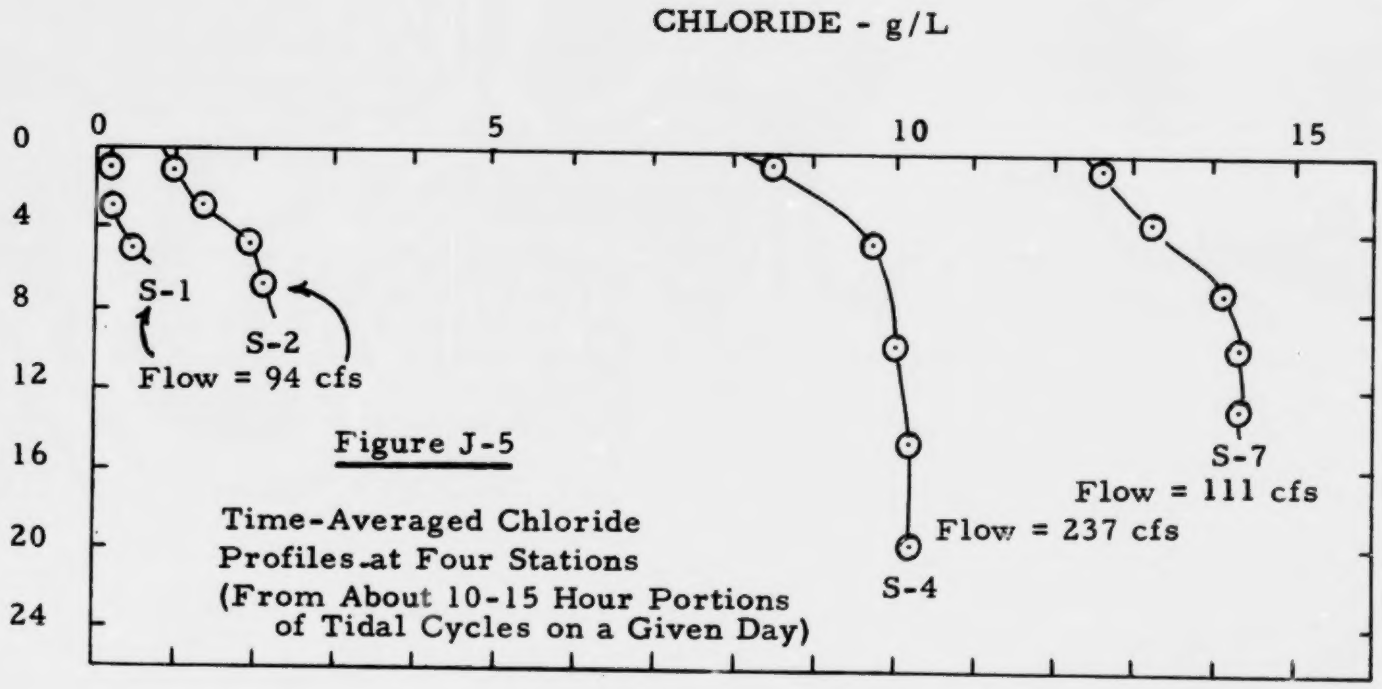


Figure J-5

Time-Averaged Chloride Profiles at Four Stations (From About 10-15 Hour Portions of Tidal Cycles on a Given Day)

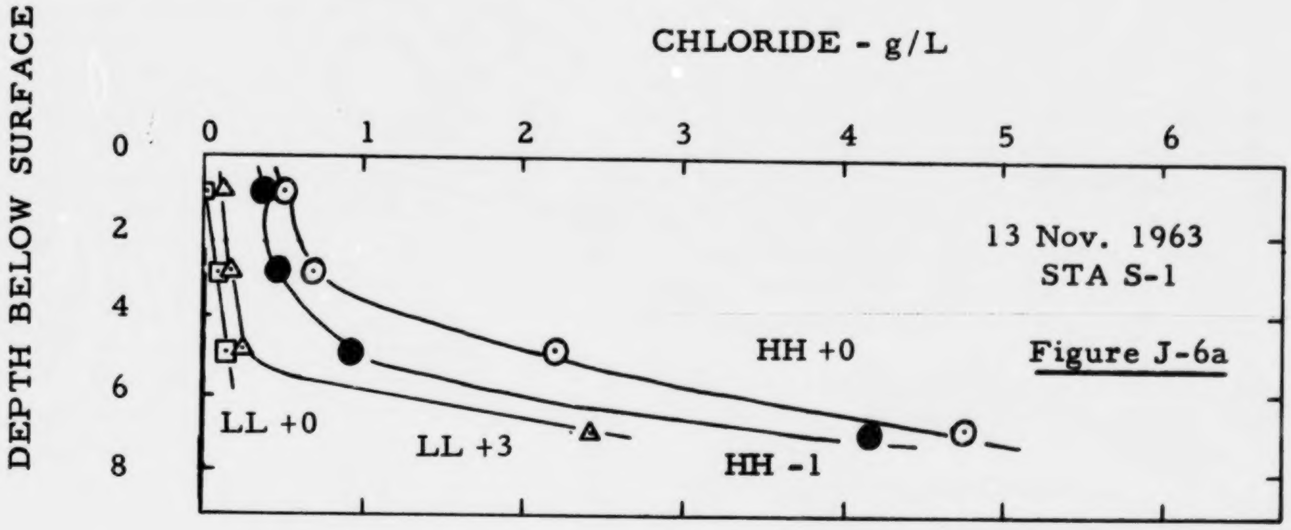


Figure J-6a

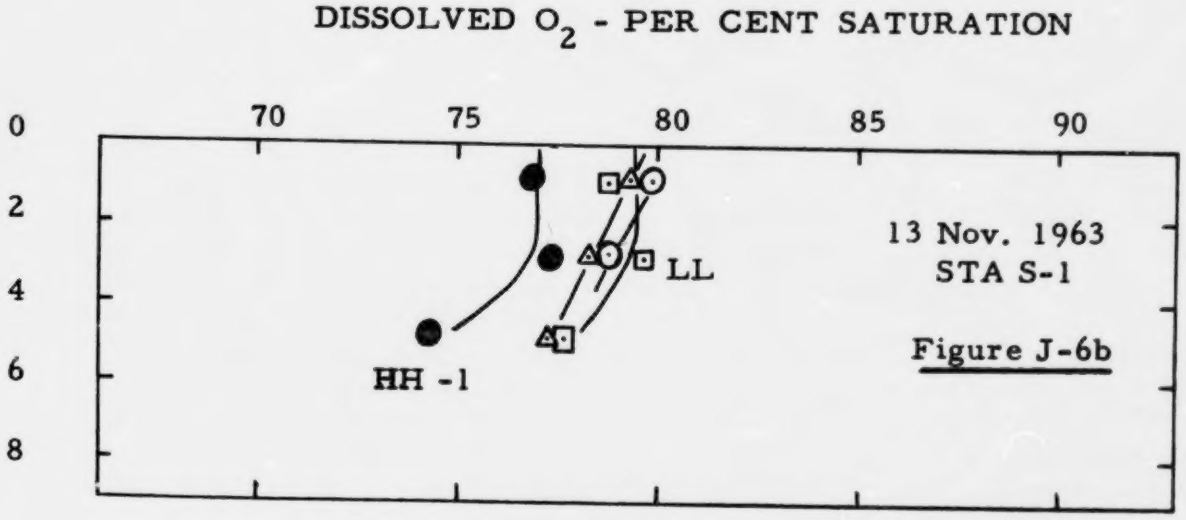


Figure J-6b

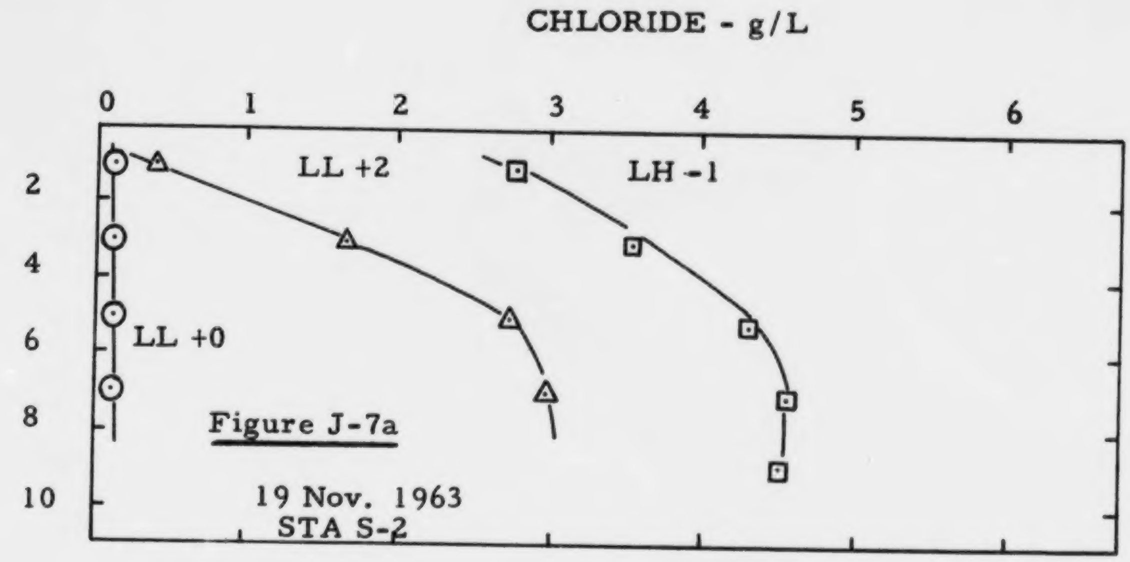


Figure J-7a

19 Nov. 1963
STA S-2

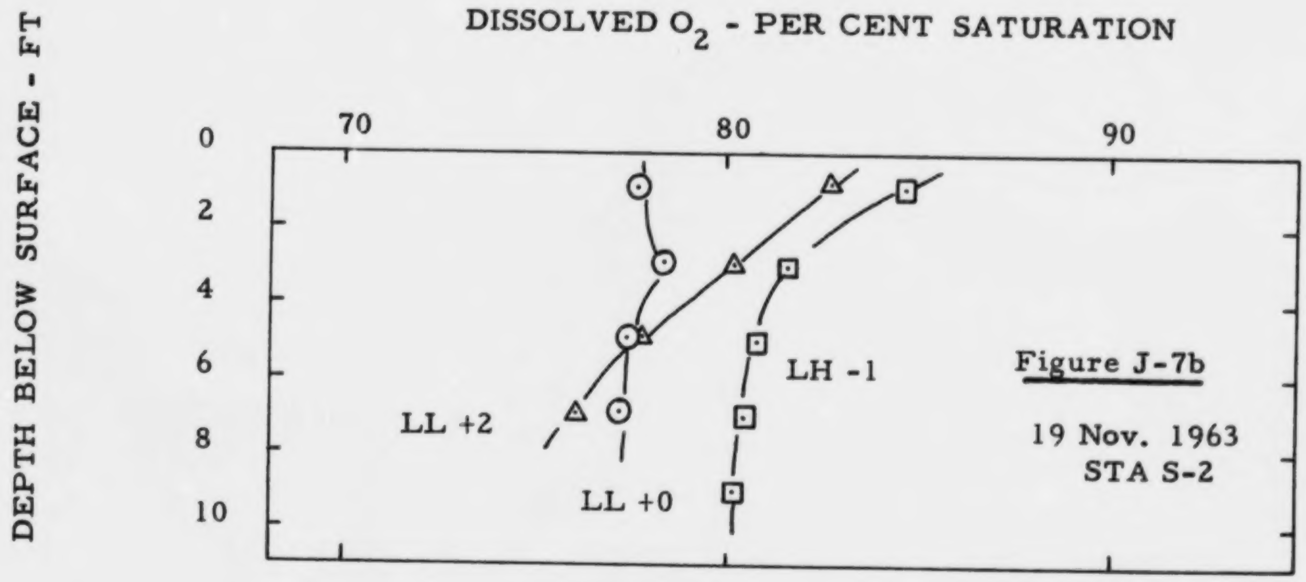


Figure J-7b

19 Nov. 1963
STA S-2

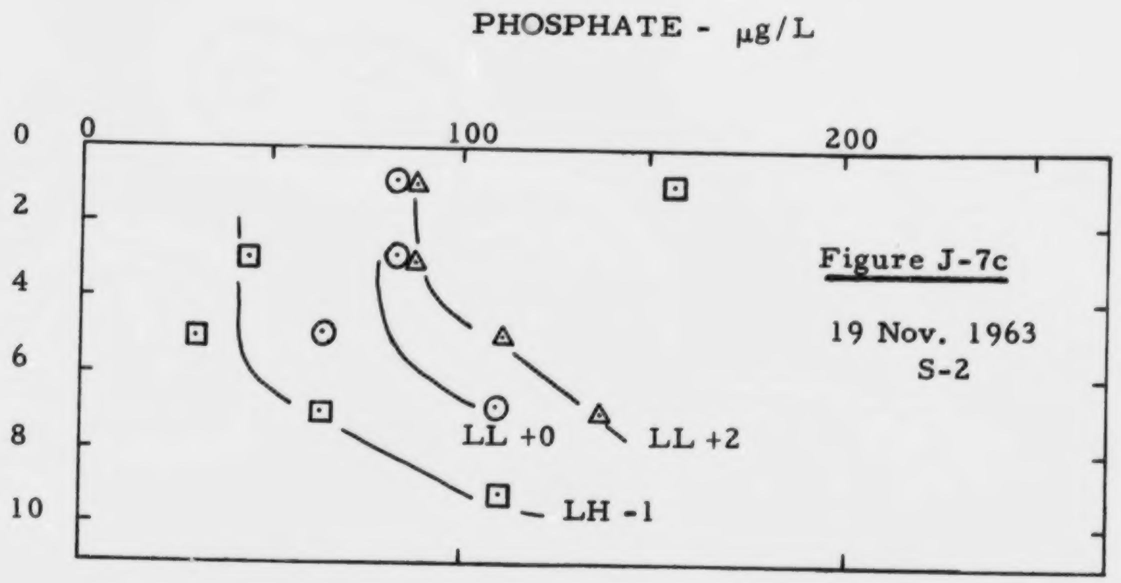


Figure J-7c

19 Nov. 1963
S-2

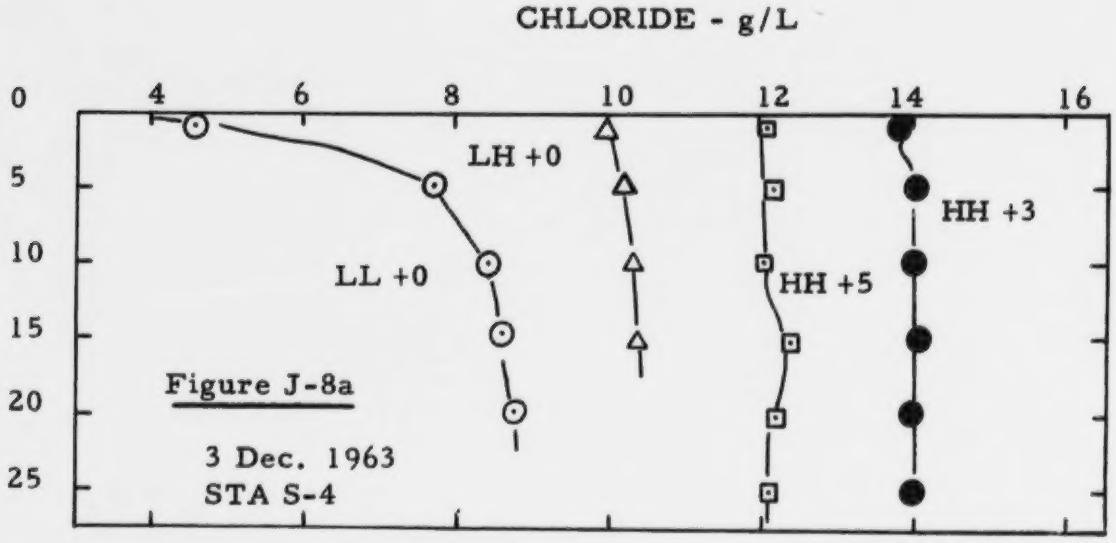


Figure J-8a

3 Dec. 1963
STA S-4

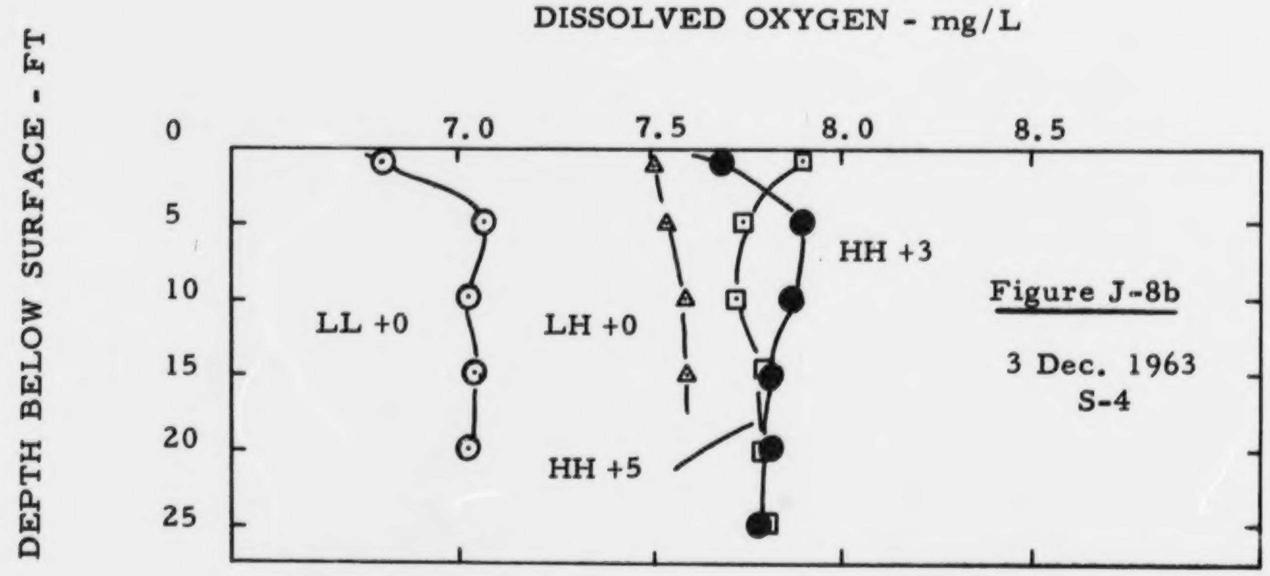


Figure J-8b

3 Dec. 1963
S-4

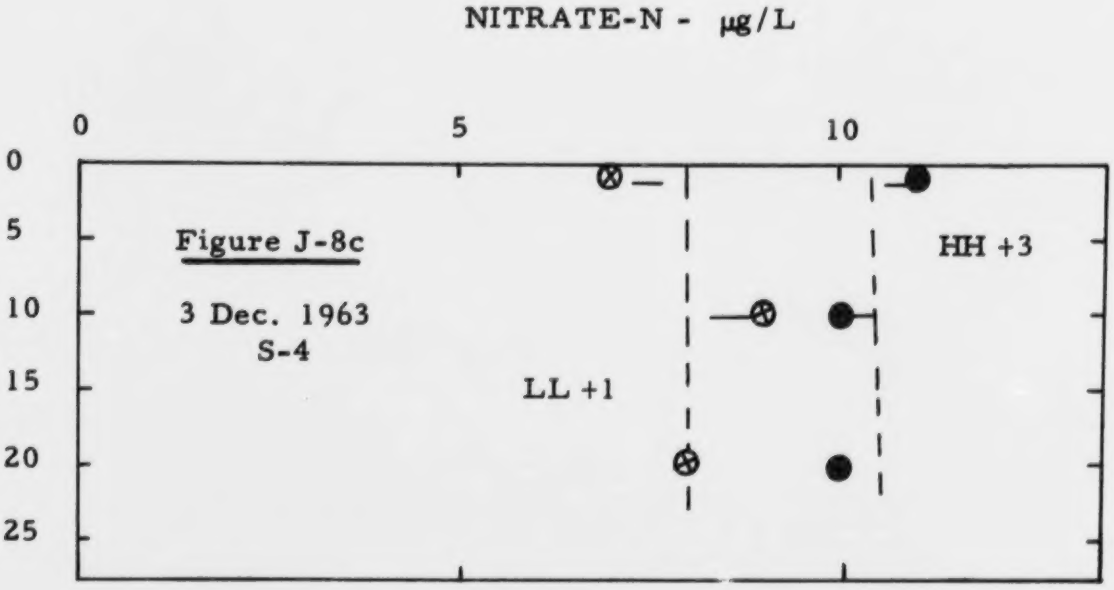
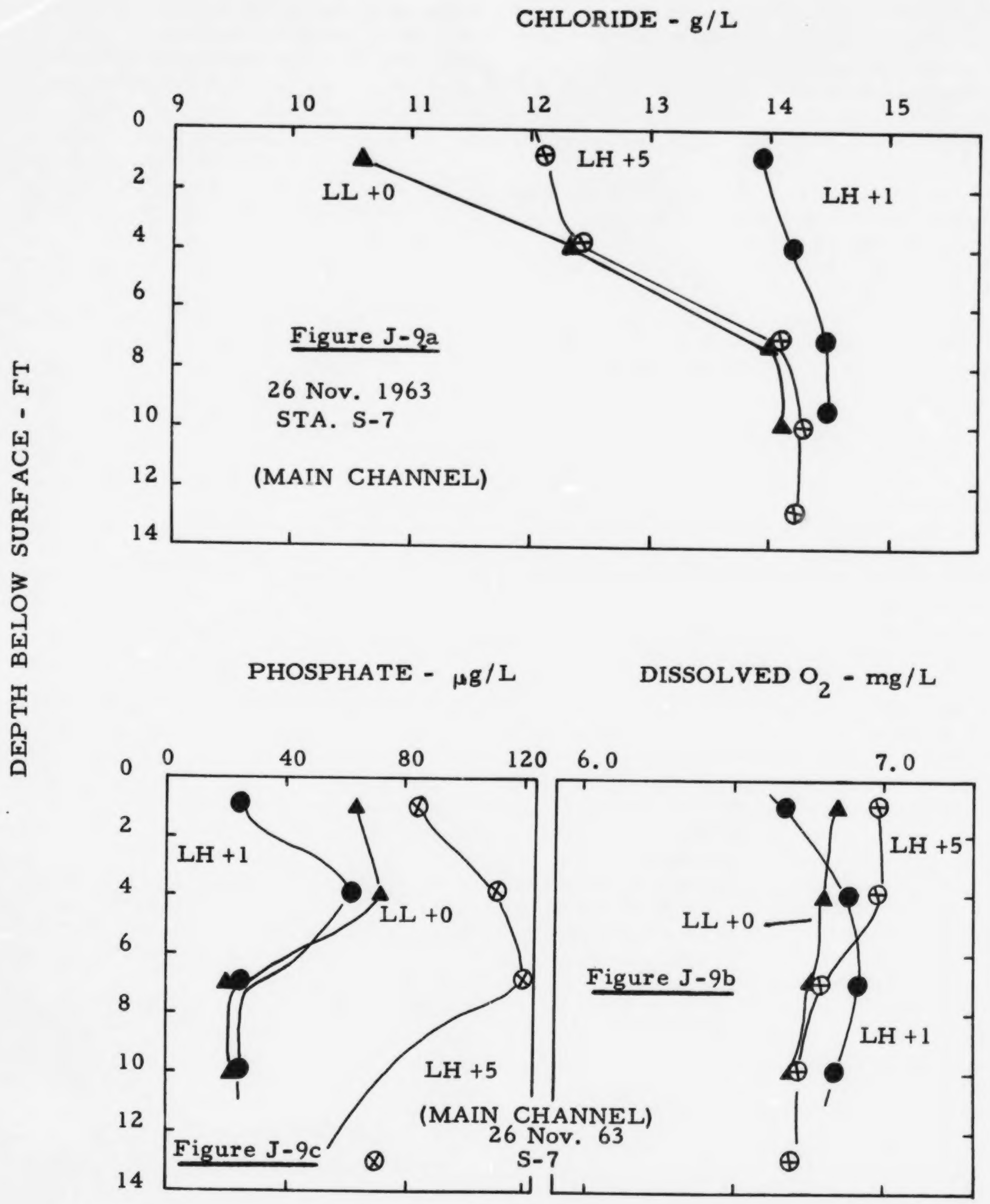


Figure J-8c

3 Dec. 1963
S-4


CHLORIDE - g/L
9
10
11
12
13
14
15
LH +5
LH +1
LL +0
Figure J-9a
26 Nov. 1963
STA. S-7
(MAIN CHANNEL)
DEPTH BELOW SURFACE - FT
0
2
4
6
8
10
12
14
PHOSPHATE - μg/L
DISSOLVED O_2 - mg/L
0
40
80
120
6.0
7.0
LH +1
LL +0
LH +5
Figure J-9c
LH +5
LL +0
Figure J-9b
LH +1
(MAIN CHANNEL)
26 Nov. 63
S-7

the extended studies indicate estuary phosphate concentrations ranging from about 20 to 100 μg PO_4 per liter.

Interpretation of nitrate concentration data is impaired since the analytical methods employed in 1963 proved unsatisfactory as indicated in Appendix 2 to this report. However, data obtained at Station 4 (Figure J-8c) suggest a nitrate concentration of about 10 μg NO_3-N per liter. The low nitrate levels in the estuary are consistent with the impression obtained from data on nitrates in both the Gulf (5) and in springs in the vicinity of the Waccasassa and Wekiva drainage areas (6) that nitrate concentrations are expectedly less than 0.1 mg/1. Nitrate levels in the Gulf have been reported to be about 30 μg/1. Both discrete and averaged data on nitrate levels in the Waccasassa obtained in this study support the idea that nitrate may be the chemical factor limiting productivity. This matter is discussed in some detail under G. PRIMARY PRODUCTIVITY.

Salinity in the Gulf

To evaluate the effects of Gulf water upon the estuary it is desirable to have information as to the salinity of the Gulf waters. In addition to the long-time U. S. Coast and Geodetic Survey salinity record (7) at Cedar Key pier, a number of salinity observations were made in the Gulf. The results of these are shown in Figure J-10. It will be noted that salinities increase markedly with distance from land. Those at Cedar Key pier are affected by fresh water discharge from the Suwannee River to the north, and those in Waccasassa Bay by discharge from the Waccasassa River and Estuary. A single series of observations on July 11, 1963, from Station 10 out into the bay ranged from a salinity of about 28°/oo at a point about 3.5 miles gulfward of Station 10 to 29.6°/oo some six miles into the Gulf. These observations were made during the low flows of 1963. Salinities at Station 10 during this period averaged about 22°/oo, but during the higher flows of 1964 they averaged around 12°/oo. Winds also affect the salinity. For the purposes of this report, average deep Gulf salinity is taken as 31°/oo (17540 mg/1 Cl) and average salinity of Waccasassa Bay gulfward of Station 10 is taken as 26°/oo (14650 mg/1 Cl). Comments on Gulf salinities offshore from the Fenholloway Estuary are made under FJ. CHEMICAL CHARACTERISTICS.

The Influence of Fresh Water Flow on Profiles

High streamflow, especially when accompanied by storm winds, has a striking influence upon longitudinal and vertical profiles of chloride, color, BOD, and other constituents of the estuary water. Table J-1 presents the results of chloride sampling on January 29, 1964, representing ordinary severe flood conditions, and on September 17, 1964, following the extraordinary flood associated with Hurricane Dora. For comparison, average high and low tide data are given. The data for the two flood conditions are entered in the high tide column for convenience, but the observations were made during a half tide cycle. Actually during severe flood conditions tide has little effect, and as shown in Figure D-5, the combination of high runoff plus wind effects may virtually eliminate tide influences in the upper part of the estuary.

From Table J-1 can be seen that severe floods can produce virtually fresh water conditions from Stations 1 to 6 inclusive. Assuming average bay salinity of 26°/oo (14650 mg/1 chlorides), the effects of flood runoff are as follows:

Station	Date	Chlorides mg/1	Per Cent Bay Water
10	Average	12800	87
	1/29/64	6750	46
	9/17/64	1250	8.5
6	Average	8470	58
	1/29/64	108	0.74
	9/17/64	10	0.07

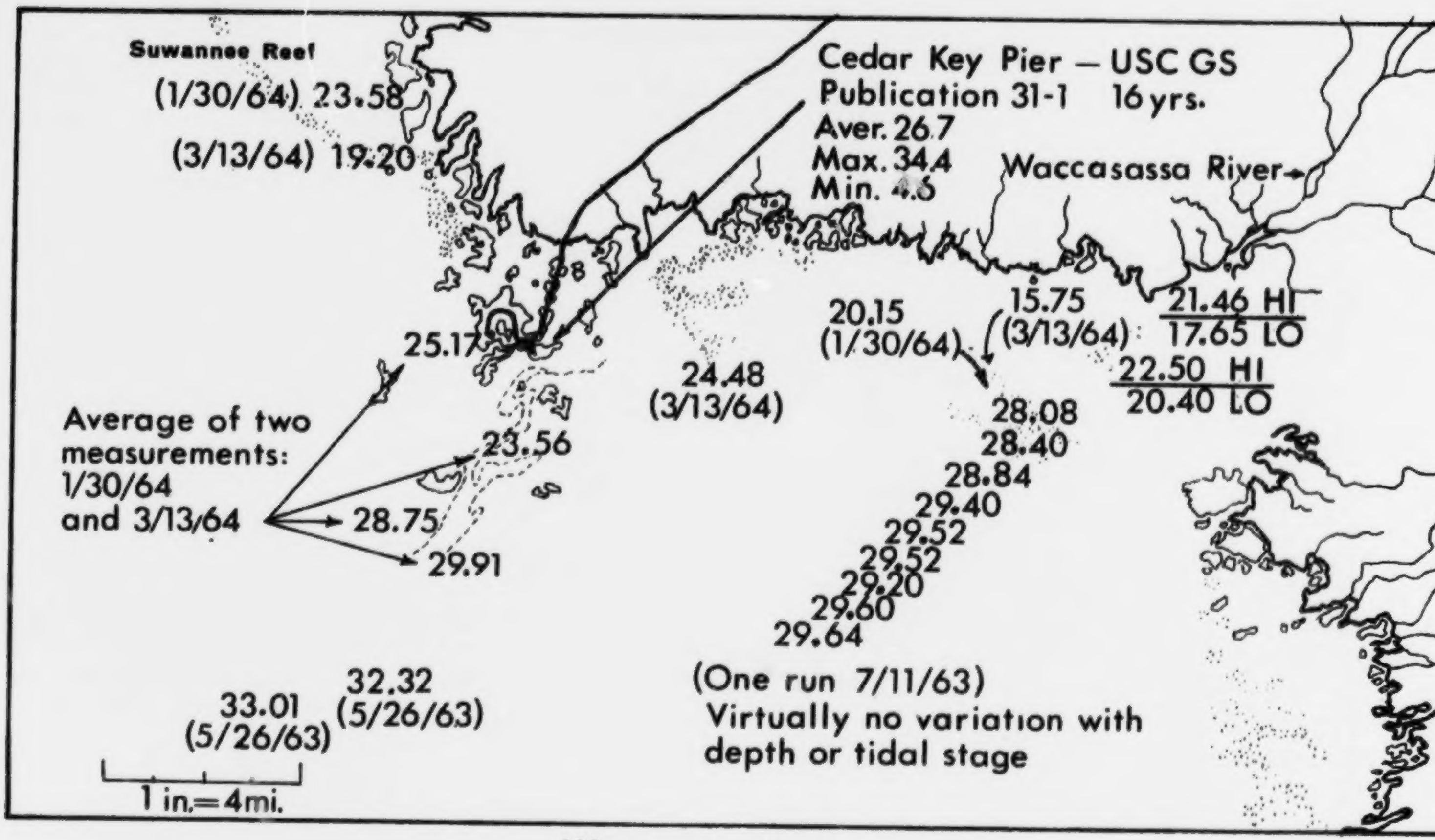
The averages given in Table J-1 are for the very low flow conditions of 1963. The average chloride value of 18 surface samples at Station 10 in 1963 was 12325 mg/1 with an average flow of 128 cfs. The average of 11 samples in 1964 was 6629 mg/1 with an average flow of 1340 cfs.

Severe floods produce other interesting effects. On January 29, 1964, there was a two- to three-fold increase in BOD in the estuary, although the level remained low at from 2 to 4 mg/1. There is evidence of a small but definite DO sag at Station 4. The DO profile dropped from 65 per cent saturation at Station 1 to 60 per cent at Station 4, with recovery to 65 per cent at Station 6 and 90 per cent at Station 10. These phenomena are presumably due to the flushing in of pollution from sources in the upper portion of the estuary as described under H. SANITARY SURVEY. Color levels were increased greatly under high flow conditions, and turbidity was somewhat lower than at ordinary flows.

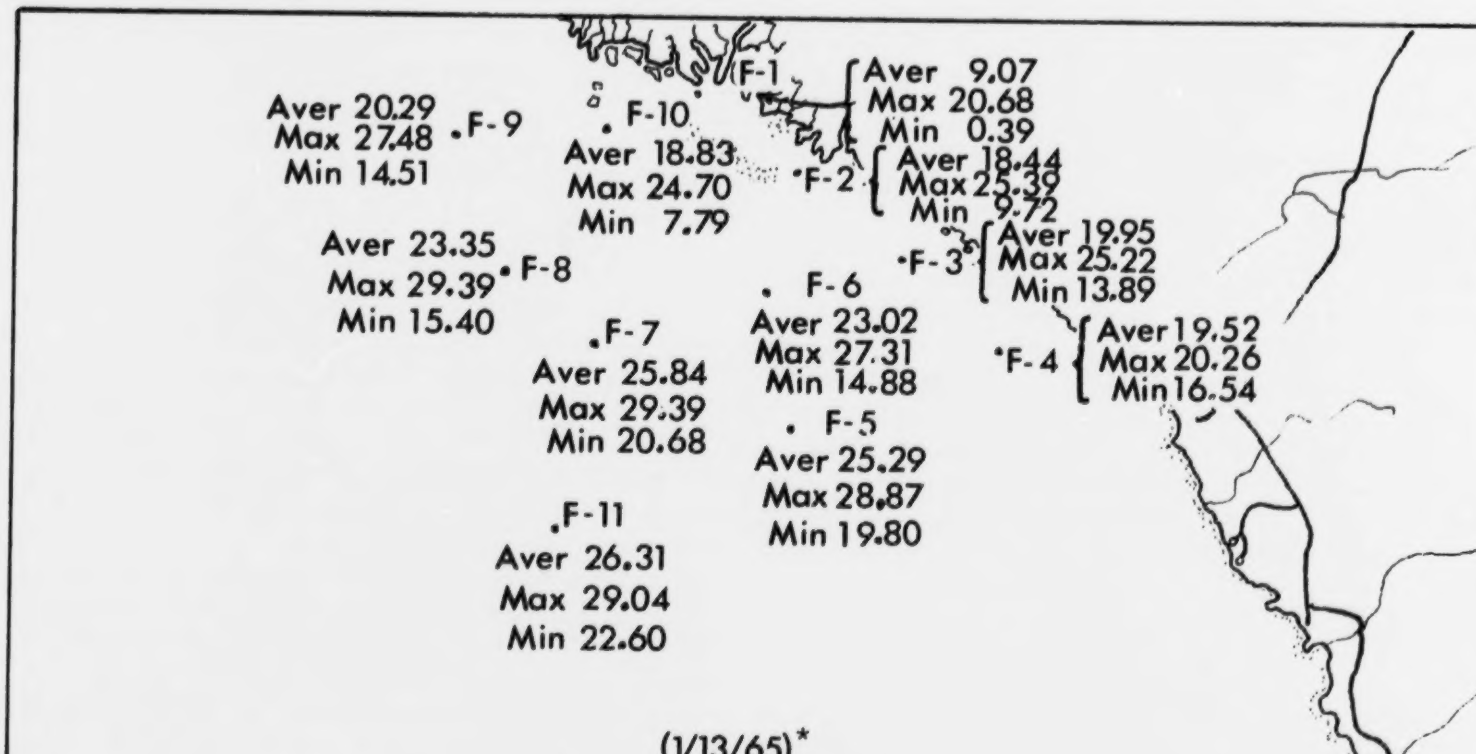
The average values in Table J-1 also show the normal effects of low and moderate fresh water runoff. The overrunning of fresh over salt water is indicated and also the lower salinities at low tide.

Summary and Conclusions

Under conditions of low fresh water flow (on the order of 100-150 cfs), the Waccasassa Estuary may be characterized as a moderately stratified estuary. Toward the fresh water end of the estuary the structure somewhat resembles the salt-wedge type, while toward the salt water end there is almost complete vertical mixing at the


Suwannee Reef
(1/30/64) 23.58
(3/13/64) 19.20
Cedar Key Pier — USC GS
Publication 31-1 16 yrs.
Aver. 26.7
Max. 34.4
Min. 4.6
Waccasassa River
25.17
Average of two measurements:
1/30/64
and 3/13/64
23.56
28.75
29.91
24.48
(3/13/64)
20.15
(1/30/64)
15.75
(3/13/64)
21.46 HI
17.65 LO
22.50 HI
20.40 LO
28.08
28.40
28.84
29.40
29.52
29.52
29.20
29.60
29.64
(One run 7/11/63)
Virtually no variation with depth or tidal stage
33.01
(5/26/63)
32.32
(5/26/63)
1 in.=4mi.

Waccasassa Area


F-1
Aver 9.07
Max 20.68
Min 0.39
Aver 20.29
Max 27.48
Min 14.51
F-9
F-10
Aver 18.83
Max 24.70
Min 7.79
F-2
Aver 18.44
Max 25.39
Min 9.72
Aver 23.35
Max 29.39
Min 15.40
F-8
F-3
Aver 19.95
Max 25.22
Min 13.89
F-6
Aver 23.02
Max 27.31
Min 14.88
F-7
Aver 25.84
Max 29.39
Min 20.68
F-4
Aver 19.52
Max 20.26
Min 16.54
F-5
Aver 25.29
Max 28.87
Min 19.80
F-11
Aver 26.31
Max 29.04
Min 22.60
(1/13/65)*
31.80 (1ft)
32.15 (25ft)
31.46 (1ft)
31.63 (21ft)
30.94 (1ft)
31.11 (21ft)
1 in.=4 mi.
* one run only

Fenholloway Area

Figure J-10
NEAR SHORE GULF SALINITIES

high water slacks and only partial vertical mixing at low water slacks. At flows of an order of magnitude greater than those which prevailed during the greater part of 1963, the estuary exhibits predominantly fresh water stream character; considerations of vertical mixing are then relatively unimportant. Similarly, longitudinal mixing (eddy diffusivity effects) is seen to be of markedly less significance under high fresh water flow conditions. Advective forces tend to govern the distribution of properties in the estuary.

For the relatively unpolluted condition of the Waccasassa which existed throughout the period of the investigation, with the attendant absence of appreciable concentration gradients longitudinally, the existence of incomplete vertical mixing is not reflected in appreciable vertical concentration gradients of most properties other than salinity. Thus the data obtained in the weekly routine sampling program are useful directly in describing the behavior of the estuary, if due regard is given to the comparability of the slack conditions at which sampling was conducted at the different stations. However, future sampling of this estuary or similar ones under conditions of significant pollution must take into account the existence of vertical concentration profiles during periods of low fresh water flow. A preliminary program of extended sampling at different depths and defined slack conditions at representative longitudinal stations is indicated as valuable in studies of polluted estuaries.

K. DIFFUSION AND POLLUTION ASSIMILATION

Introduction

One of the major objectives of the project was to utilize the analytical data and the field investigations to predict the capacity of the Waccasassa Estuary to assimilate pollution. This involved consideration of a number of factors such as the length of time a pollutant remains in the estuary and what occurs to it during that time. A first approach comprises efforts to estimate the combined effects of advective and mixing processes which take place in the estuary. Advective forces (quantity and velocity of flow, etc.) are directly measurable. Mixing forces may be defined in terms of a coefficient of eddy diffusivity. The combined effects of advective and mixing forces can be represented by a differential equation which includes a factor called a tracer which simulates a pollutant.

Earlier concepts of estuarine flushing were based on the assumption that the entire intertidal volume of water in an estuary was uncontaminated sea water and was completely available by thorough mixing with the low water volume of polluted water in the estuary for dilution of the pollution. This concept was modified by Ketchum (1) by segmenting the estuary into lengths equal to the average tidal excursion of a particle, assuming complete mixing within each segment.

Later concepts involved the computation of coefficients of eddy diffusivity (E) to predict the distribution of conservative and nonconservative wastes in an estuary. The development and application of these concepts are to be found in numerous papers during the last decade, some of which are noted in items (2) to (9) inclusive in Appendix 1 under K. POLLUTION ASSIMILATION. Several of these methods have been used in the latter part of this section.

In the present study it was decided to use analyses of time and space concentrations of an internal tracer (salinity) and of an external tracer (day) in the determination of E. An induction salinometer was used for salinity and temperature measurements. The external tracer selected was Rhodamine B, a fluorescent organic red dye which can be detected in very low concentrations and which seems to be completely harmless to marine life in the concentrations to be used. For the measurement of dye concentrations, a Turner Model III Fluorometer with a flow-through door was used for *in situ* readings in the estuary. Salinity and dye observations were made on the same sampling runs.

Since the analysis of the factors influencing dispersal and advection of a pollutant in an estuary is an exceedingly complex problem, susceptible at best of only imprecise quantitative results, several approaches to its solution have been attempted in the present study. These are briefly discussed below.

Coefficient of Diffusivity by Internal Tracer

Two procedures were used to compute the diffusivity coefficient E utilizing salinity (chloride ion) as an internal tracer. The first is based upon a one dimension differential equation reported by Selleck and Pearson (7). Data obtained on the mean values of salinity between Station 0 and Station 280 (Tide Gages T-I and T-VI, Figure K-1) were analyzed to determine the value of E for three three-day periods, one each in August, September, and October, 1963. Although it was expected that there would be some variation of river flow for these periods, it developed that all were periods of low flow attributable principally to the flow of Wekiva and Blue Springs and a small, steady ground water flow. Thus the best estimate of flow by several independent means indicated approximately 100 cubic feet per second at Gage T-I, with gradually increasing flow due to ground water and marsh seepage to a total estimated flow at Gage T-VI of 150 cubic feet per second.

The one-dimensional differential equation for diffusion and advection of a tracer in an estuary is given by:

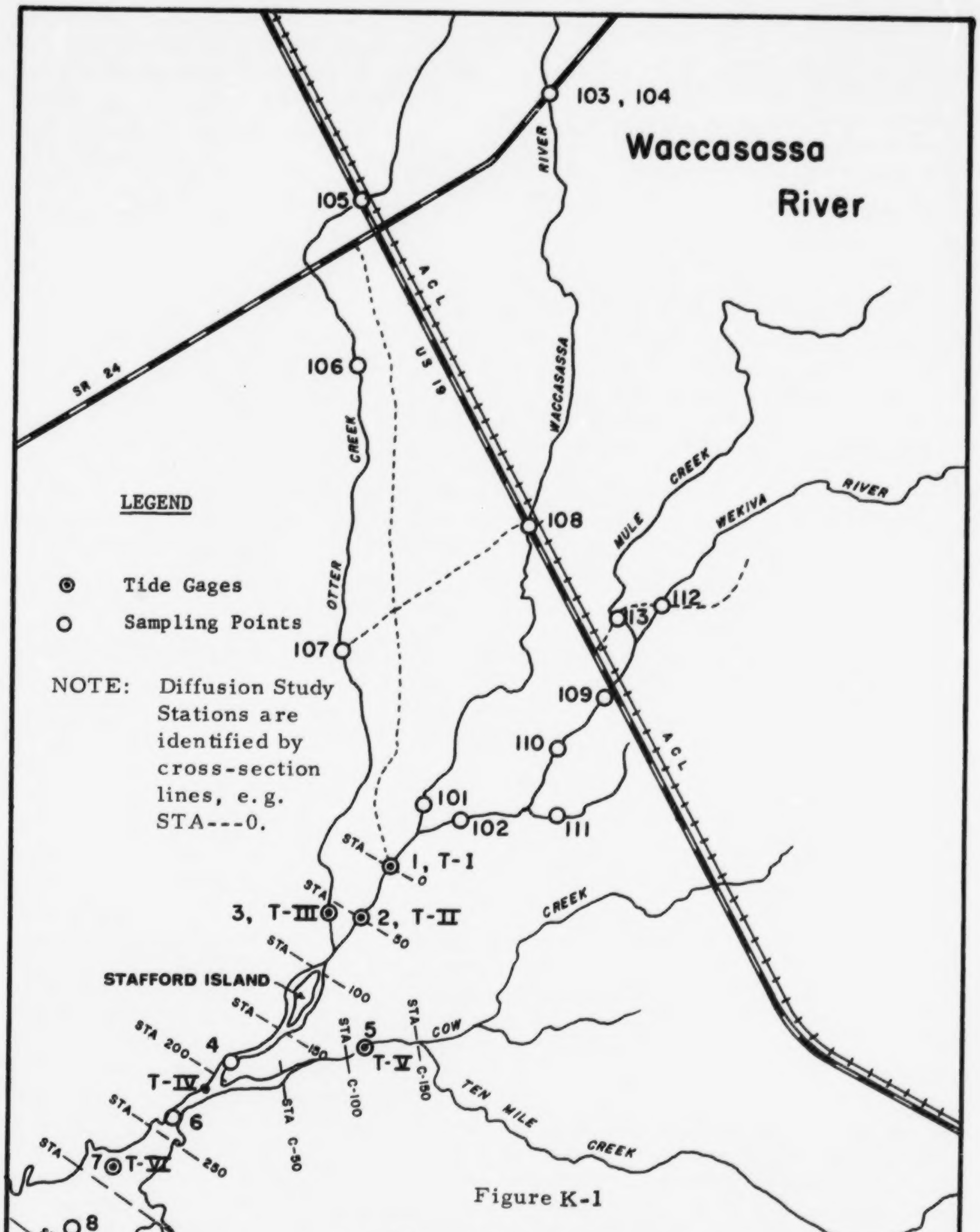

Waccasassa
River
103, 104
105
106
107
108
109
110
101
102
111
113
112
1, T-1
2, T-II
3, T-III
4
T-IV
5
T-V
6
7 T-VI
8
9
10
SR 24
ACL
US 19
RIVER
WACCASASSA
OTTER
CREEK
MULE
CREEK
WEKIVA
RIVER
CREEK
COW
TEN
MILE
CREEK
STAFFORD ISLAND
WACCASASSA
BAY
STA 0
STA 50
STA 100
STA 150
STA 200
STA 250
STA 300
STA 350
STA C-50
STA C-100
STA C-150
LEGEND
Tide Gages
Sampling Points
NOTE: Diffusion Study Stations are identified by cross-section lines, e.g. STA---0.
MILES
0
1
2
3

Figure K-1

Location of Tide Gages, Sampling Points & Diffusion Study Stations

$$F(x,t) = O \cdot c - A \cdot E \, dc/dx$$

where $F(x,t)$ = net rate of mass transfer of tracer across the cross-section at x
O = net advective flow
E = eddy diffusivity coefficient
c = concentration of tracer

If tracer concentrations are obtained at slack waters, quantities in the above equation may be replaced by mean values where the bar stands for the mean value, thus:

$$\bar{F}(x,t) \cong \bar{O} \cdot \bar{c} \cong \bar{A} \cdot \bar{E} \, \overline{(dc/dx)}$$

Under steady state conditions, the net rate of transfer across any section is zero. If sampling stations are selected to provide equal distances upstream and downstream from each cross-section being considered, the mean value for E may be determined at the station for the tidal cycle concerned by:

$$\bar{\bar{E}} \cong \frac{2\Delta x \bar{\bar{S}}_x \bar{U}}{\bar{\bar{S}}_{x+\Delta x} - \bar{\bar{S}}_{x-\Delta x}}$$

where $2\Delta x$ represents a reach of the estuary over which salinity may be taken to vary linearly

$$\bar{U} = \frac{Q}{\bar{A}}$$

$\bar{\bar{S}}_x$ = mean salinity at x

$\bar{\bar{S}}_{x+\Delta x}$ = mean salinity at a distance Δx downstream from station x

$\bar{\bar{S}}_{x-\Delta x}$ = mean salinity at distance Δx upstream from x

The above is substantially the same as the equation used by Selleck and Pearson (7) in a study of pollution in South San Francisco Bay.

The mean values obtained through the use of this finite difference equation for the reach of the river from Station 100 to Station 240 (Figure K-1) were:

August 7-9, 1963	E = 2.34 square miles per day
Sept. 11-13, 1963	E = 2.45 square miles per day
October 16-18, 1963	E = 2.49 square miles per day

Another method of determining E from salinity data is that developed by Professors D. J. O'Connor and J. P. Lawler of Manhattan College as consultants for this study.* From the salinity data diffusivity coefficients were computed utilizing the equation:

$s = s_o e^{\frac{(Q/EA_o)(1-e^{-ax})}{a}}$, where s and s_o are the relative salinities at any cross section and at the first upstream cross section (x = O), respectively. Relative salinity (a pure number) is the ratio between the salinity at any point in the estuary to the salinity at an offshore point where further increase in mean salinity becomes negligible (S_{max}).

It was determined that the Waccasassa Estuary has an exponential variation of cross-sectional area* with length as indicated on Figure K-2. Figures K-3 and K-3a show the correlation of data for the August 7-9 period both for constant discharge (125 cfs) and for continuously increasing discharge (100 cfs to 150 cfs) respectively. Similar plots have been made for the September and October periods. The equations shown on Figures K-3 and K-3a were developed by O'Connor and Lawler. The results are as follows, giving the mean values of E in terms of square miles per day:

Period	E (Constant Discharge)	E (Increasing Discharge)
Aug. 7-9, 1963	2.32	2.03
Sept. 11-13, 1963	2.30	2.07
Oct. 16-18, 1963	2.70	2.46

The correlation of data using the continually increasing discharge procedure was considered best and shows reasonably good agreement with the values by the finite difference method. Plots for all three periods are shown on Figure K-4. Figure K-5 shows the high and low water mean salinity profiles during the August 7-9 period of study. The profiles for the September and October periods are similar in configuration.

Coefficient of Diffusivity by External Tracer

The determination of E from the dye dispersion data available has been made using the analysis developed by O'Connor and Lawler in the report mentioned previously. The spread of the dye concentration curves (weighted to take into consideration the increasing cross sectional areas toward the mouth of the river) as determined at any fixed tidal stage is a measure of E. Because of the short length of the estuary, a number of the dye concentration curves were peaked outside the mouth of the river on low water slacks. Only two of the slack concentration curves for each study period were suitable for correlation and determination of eddy diffusivity.

Figure K-6 shows the dye distribution curves for the period of August 7-9, 1963. From Curves 1 and 3 the logarithm of $(C \cdot A)$ the weighted concentration was plotted versus $(x)^2$, the square of the mean spread of each curve from its peak. On Figure K-7 are shown the computations used to determine E from the equation:

$\text{Log}_e (C \cdot A) = \text{Log}_e (C \cdot A)_o - \frac{(x)^2}{4Et}$, where t = time in days.

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*Mathematical Analysis of Water Quality of the Waccasassa River, Florida. Donald J. O'Connor and John P. Lawler. Appendix to separate Section K.

*Referred to Mean Tide Level.

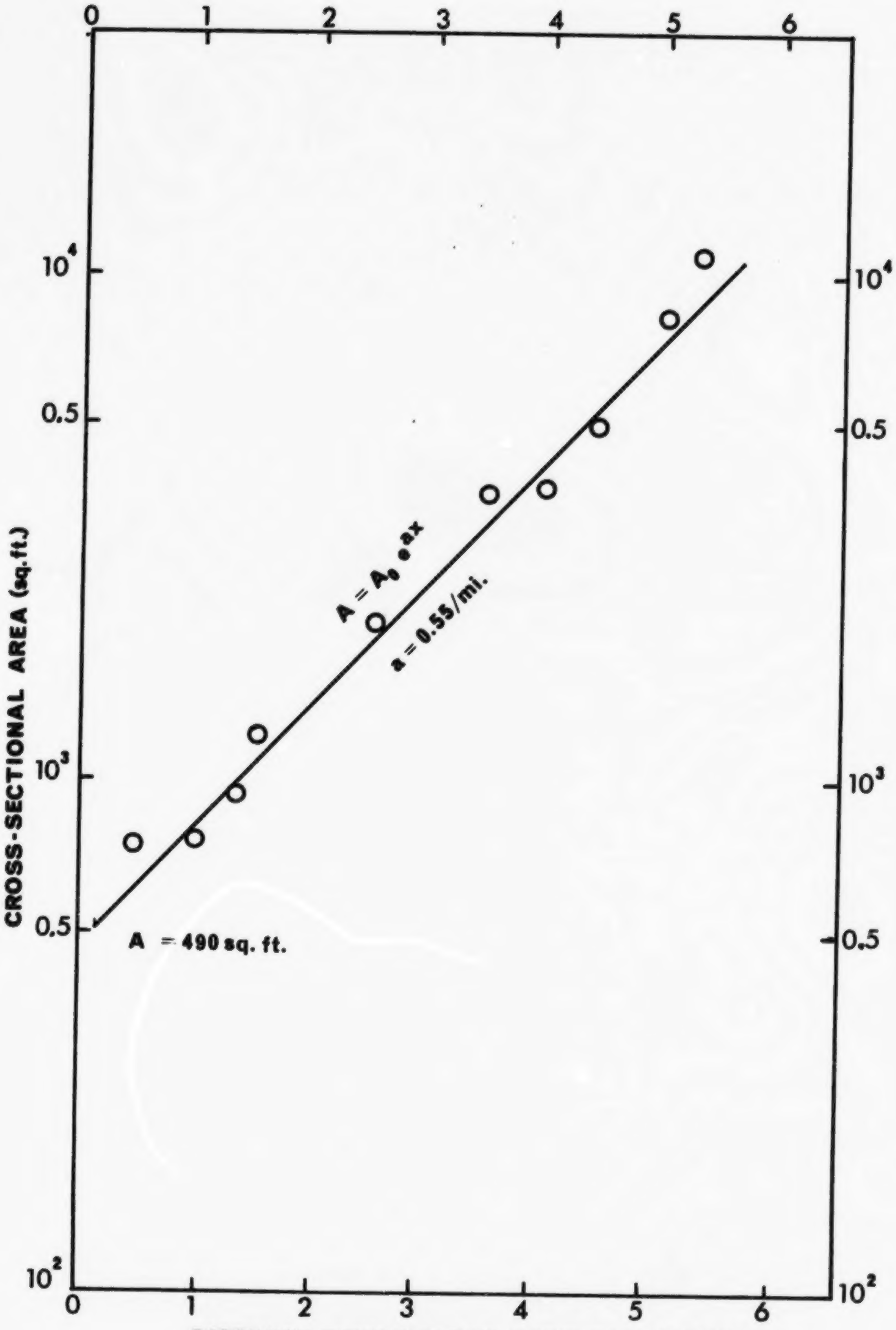

Figure K-2

Waccasassa Estuary Cross-Sectional Area Vs. Distance
October, 1963

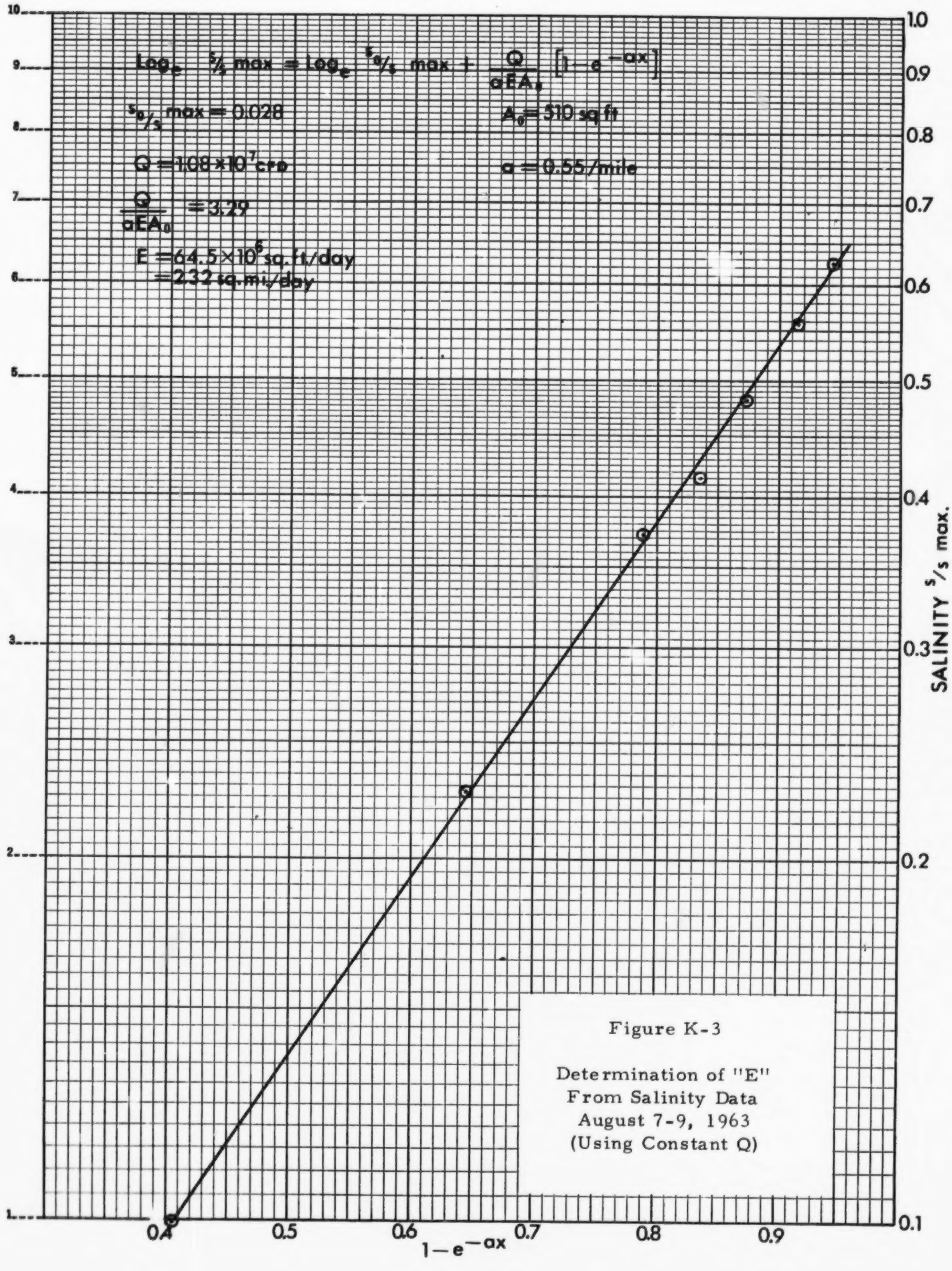

Figure K-3

Determination of "E"
From Salinity Data
August 7-9, 1963
(Using Constant Q)

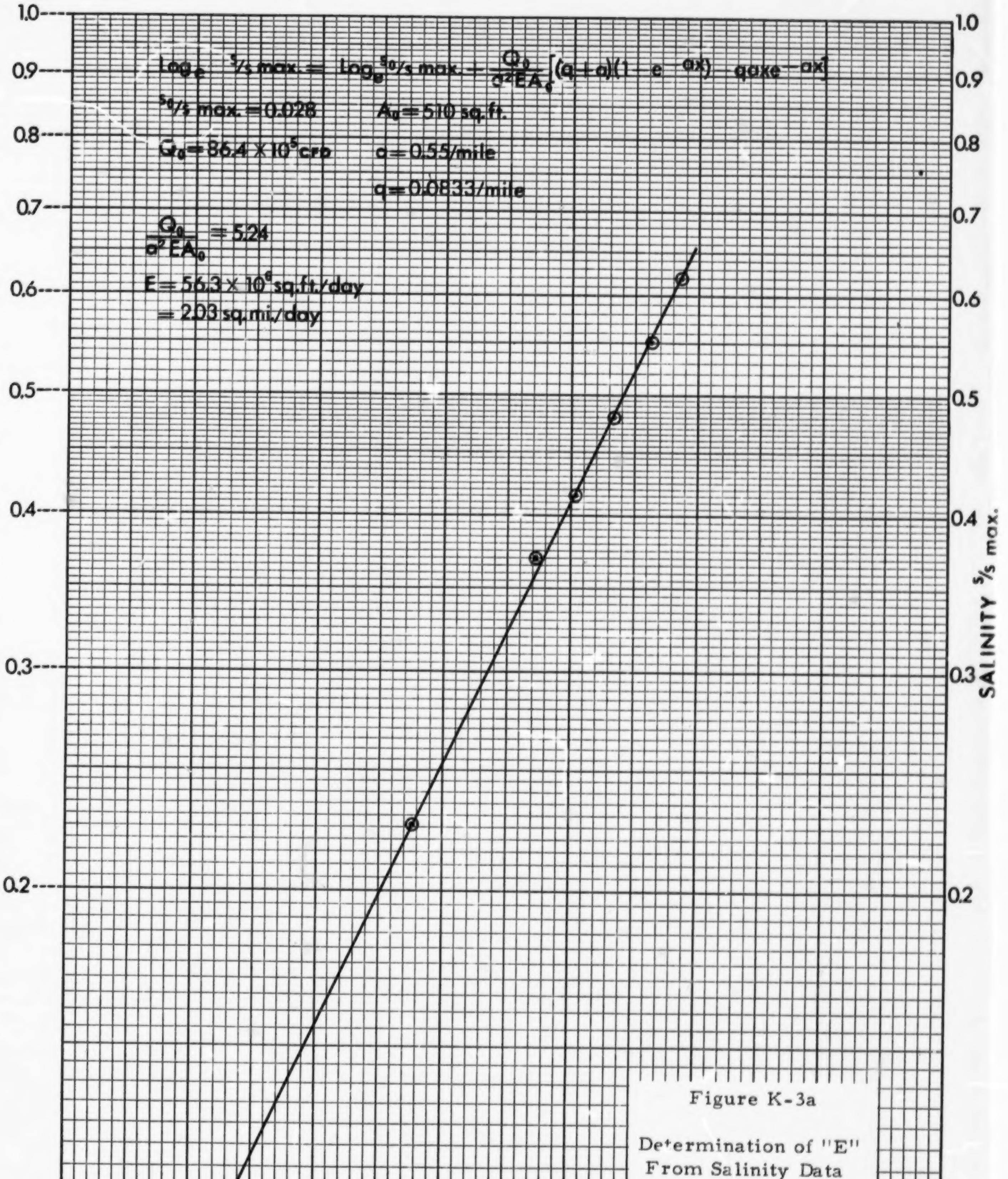

Figure K-3a

Determination of "E"
From Salinity Data
Aug. 7-9, 1963
(Using Increasing Q)

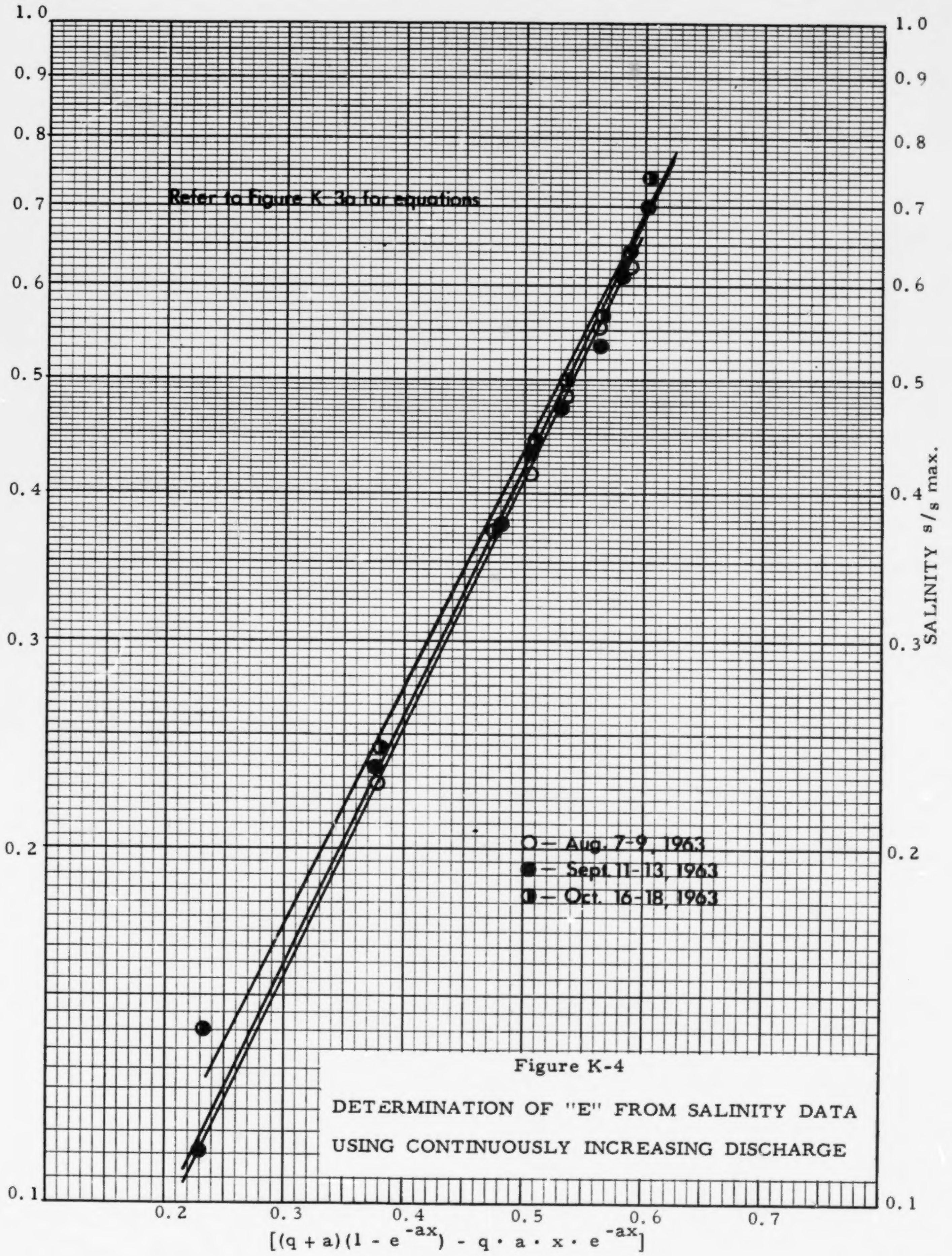

Figure K-4

DETERMINATION OF "E" FROM SALINITY DATA USING CONTINUOUSLY INCREASING DISCHARGE

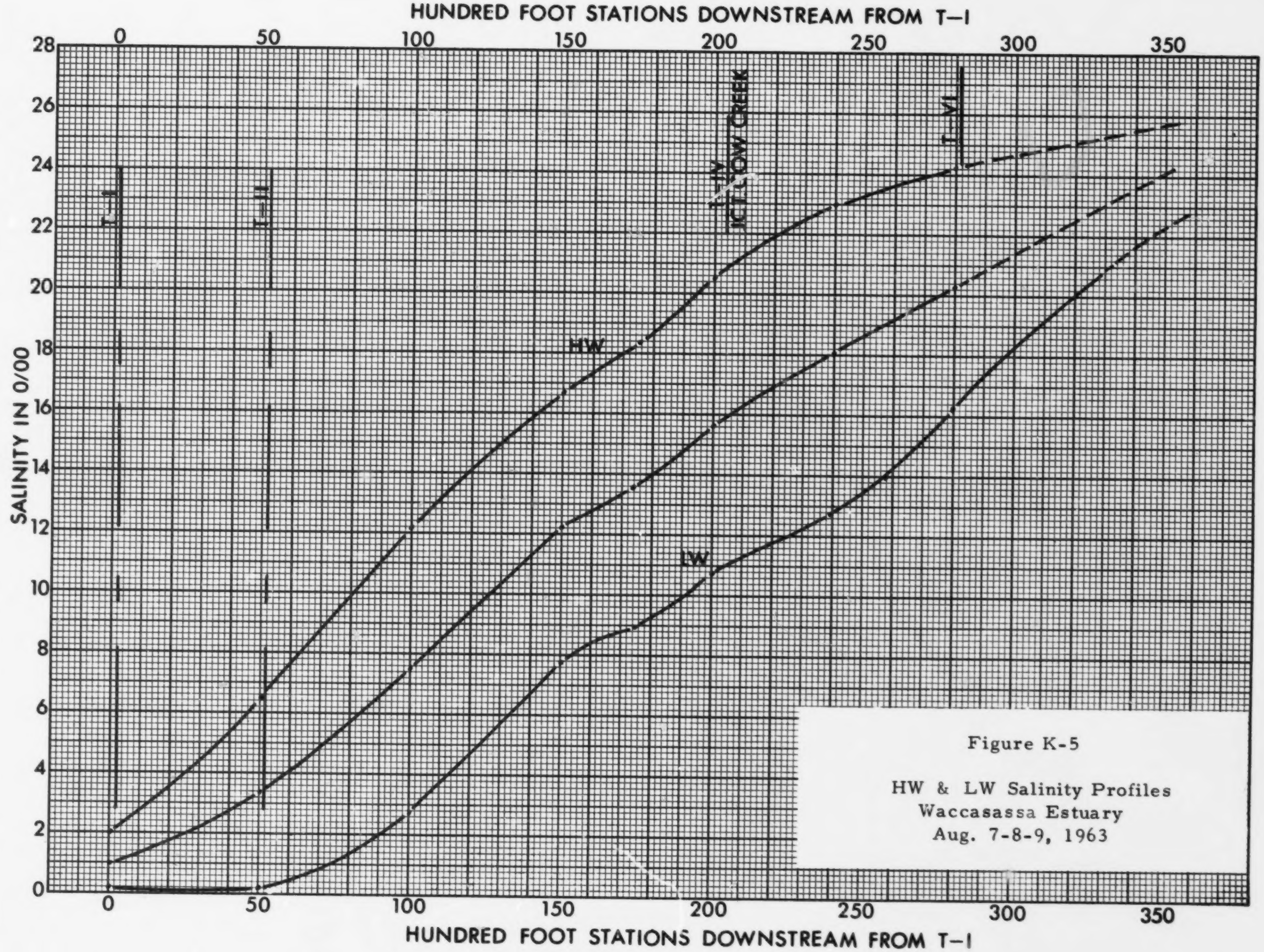

Figure K-5

HW & LW Salinity Profiles
Waccasassa Estuary
Aug. 7-8-9, 1963

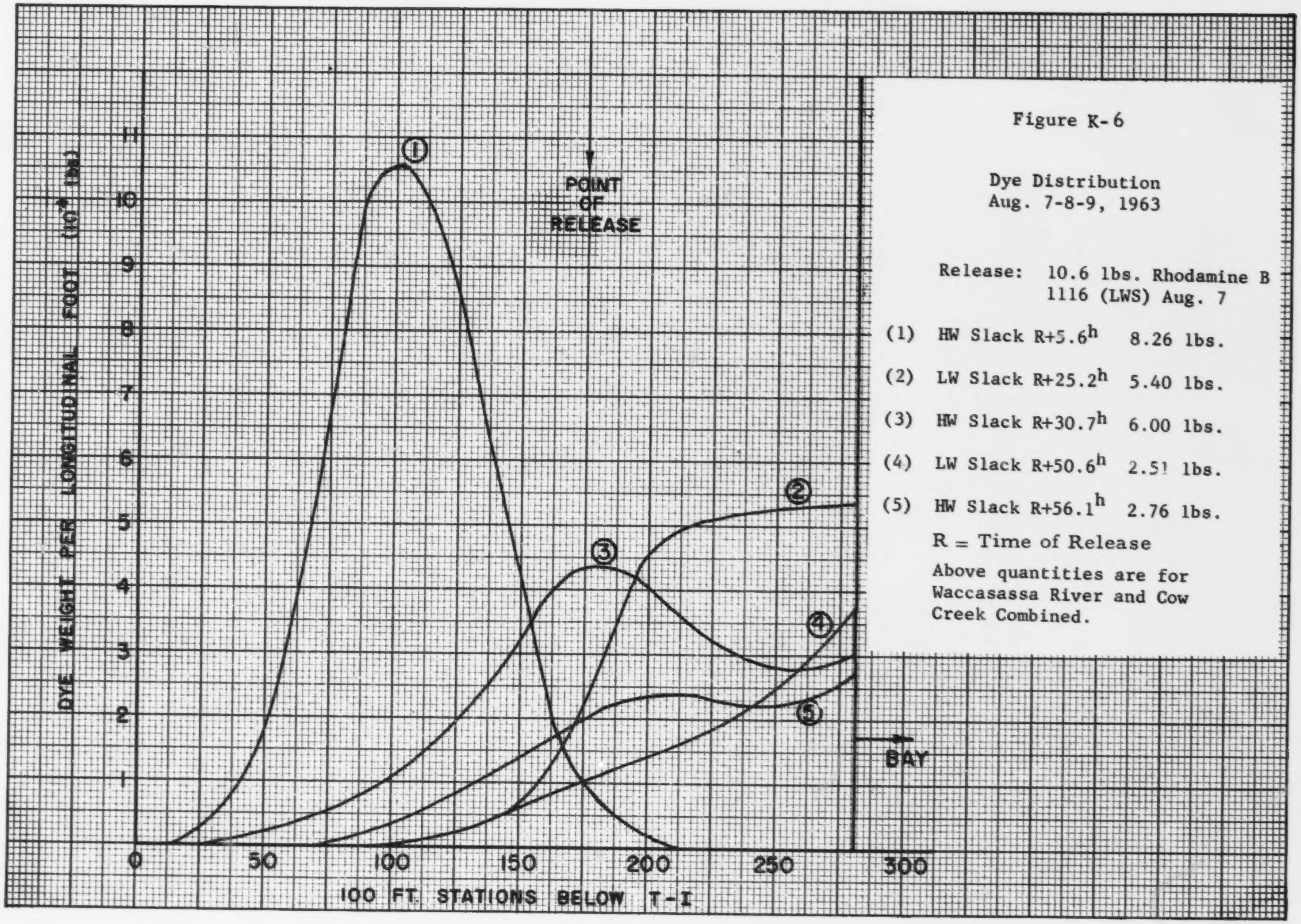

Figure K-6

Dye Distribution
Aug. 7-8-9, 1963

Release: 10.6 lbs. Rhodamine B
1116 (LWS) Aug. 7

(1) HW Slack R+5.6^h 8.26 lbs.

(2) LW Slack R+25.2^h 5.40 lbs.

(3) HW Slack R+30.7^h 6.00 lbs.

(4) LW Slack R+50.6^h 2.51 lbs.

(5) HW Slack R+56.1^h 2.76 lbs.

R = Time of Release

Above quantities are for Waccasassa River and Cow Creek Combined.

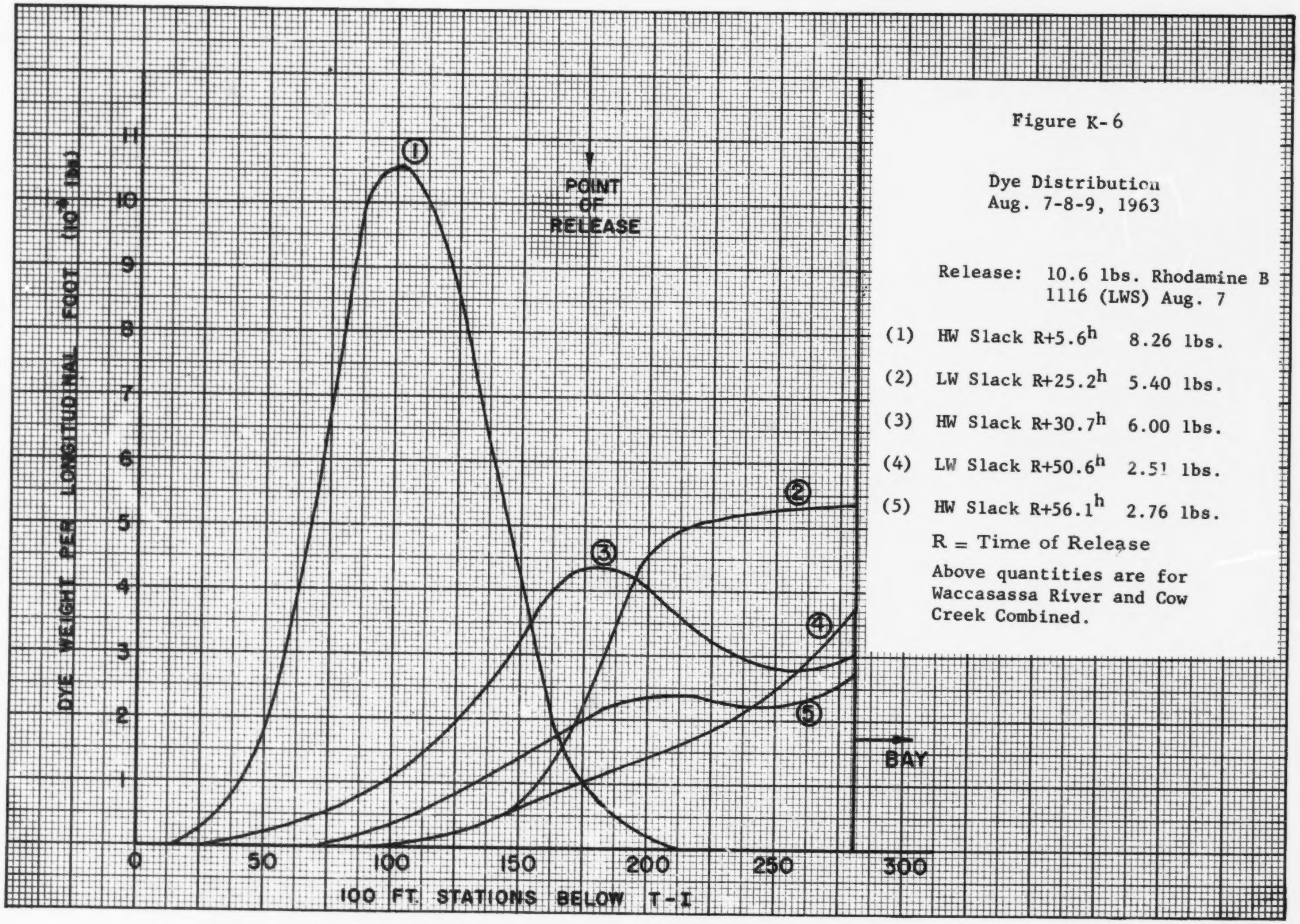

Figure K-6

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Aug. 7-8-9, 1963

Release: 10.6 lbs. Rhodamine B
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Above quantities are for Waccasassa River and Cow Creek Combined.

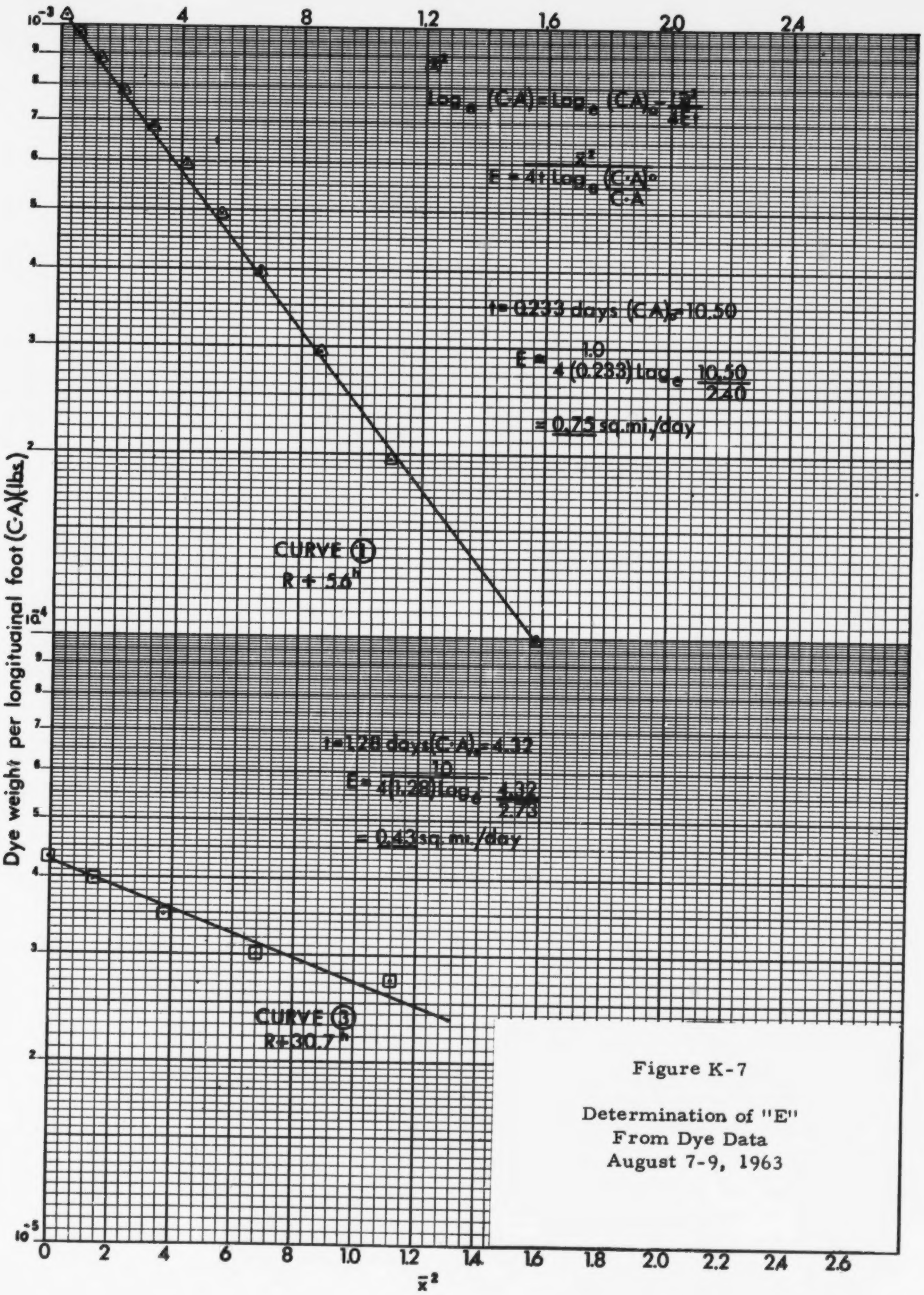

Figure K-7

Determination of "E"
From Dye Data
August 7-9, 1963

The values of E as computed from these curves are as follows:

	August 7-9, 1963
Curve 1	E = 0.75 square miles per day
Curve 3	E = 0.43 square miles per day
	September 11-13, 1963
Curve 2	E = 0.32 square miles per day
Curve 3	E = 0.25 square miles per day
	October 16-18, 1963
Curve 1	E = 0.67 square miles per day
Curve 3	E = 0.51 square miles per day

The values of E as determined by the dye distribution curves are considerably lower than those obtained from the salinity distribution. The configuration of the dye curves indicates that there was an indeterminate exchange of dye between the river and the bay outside the mouth. Differences between the values of diffusion coefficients determined from dye and salinity studies have been noted previously by O'Connor.* The value of E as determined by the one-dimensional mass transport equation used for the salinity correlations is somewhat too large because of density differences between fresh and salt water near the mouth of an estuary.

It is considered that the value of E during the periods of low river flows which were studied lies between the values obtained from salinity and dye diffusion data, but closer to that determined from the salinity distribution. A value of 2.0 square miles per day is believed to be reasonable from the data obtained.

Pollution Assimilation Characteristics

One way in which to estimate the ability of an estuary to rid itself of waste accumulations is to determine the flushing time, or mean residence time, of an average particle of pollution. This time must necessarily be valid only for a given set of conditions of streamflow and tidal action.

The mean residence or detention time of a particle of waste can be estimated by determining the mean quantity of fresh water in a given section of the estuary under steady state conditions and dividing by the best estimate of fresh water advective flow into the section. On this basis the following estimates of mean detention time by section during low flow conditions such as existed in August, September, and October, 1963, can be stated:

Section	Mean Detention Time
Station 0-100 (T-I to Upper End, Stafford Island)	1.10 days
Station 100-200 (Upper End, Stafford Island to Cow Creek)	1.16 days
Station 200-280 (Cow Creek to T-VI)	2.14 days
Total, T-I to T-VI	4.40 days

Another manner of indicating the flushing of wastes is to predict a steady-state distribution of a conservative or nonconservative pollutant. Stommel (2) has developed a method of relating the fluxes due to net advection and to turbulent diffusion in such a way as to permit solution of the diffusion equation by relaxation methods. This method was used to obtain the distribution of concentrations of a nonconservative pollutant introduced at Station 50 (T-II). A half-life of four days was used and the flow of pollutant was taken as 7000 pounds per day, which would be equivalent to the ultimate BOD from a city of approximately 50,000 with primary treatment of its sewage. The pollutant is skewed downstream from the source under the influence of the river discharge. The maximum concentration is approximately 5 mg/liter at the source, and the concentration reduces to essentially zero two miles upstream and four miles downstream as indicated on Figure K-8.

The effect of wastes which may be added to an estuary on the dissolved oxygen level at various points within the estuary is one of the principal aspects of waste distribution under the influence of diffusion and advective flow. The Waccasassa Estuary can be described as partially mixed. The salinity gradients approach the completely mixed state in the higher portion of the tidal cycle but show the effect of density currents increasing the salinity gradient in the lower portion. The vertical dissolved oxygen gradient is low, indicating considerable mixing. The rates of oxygen loss by biological processes and gain by reaeration are similar to those of upland streams.

O'Connor (9) has developed an approach to predicting the oxygen distribution in a well-mixed estuary, assuming constant forward velocity and a constant value of eddy diffusivity. These conditions are never realized in an actual estuary, but within the four miles of estuary between Stations 50 and 250 (Figure K-1), the estuary geography permits reasonable conformity with the assumptions.

Assuming a source of wastes located at Tide Gage T-II (Station 50), dissolved oxygen profiles were computed for 20°C and 30°C by the O'Connor procedure. The initial oxygen deficit was taken as 1.0 mg/liter.

The initial concentration of BOD was taken as 10 mg/liter, which is equivalent to 15,500 pounds of ultimate

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*See Appendix A to separate Section K.

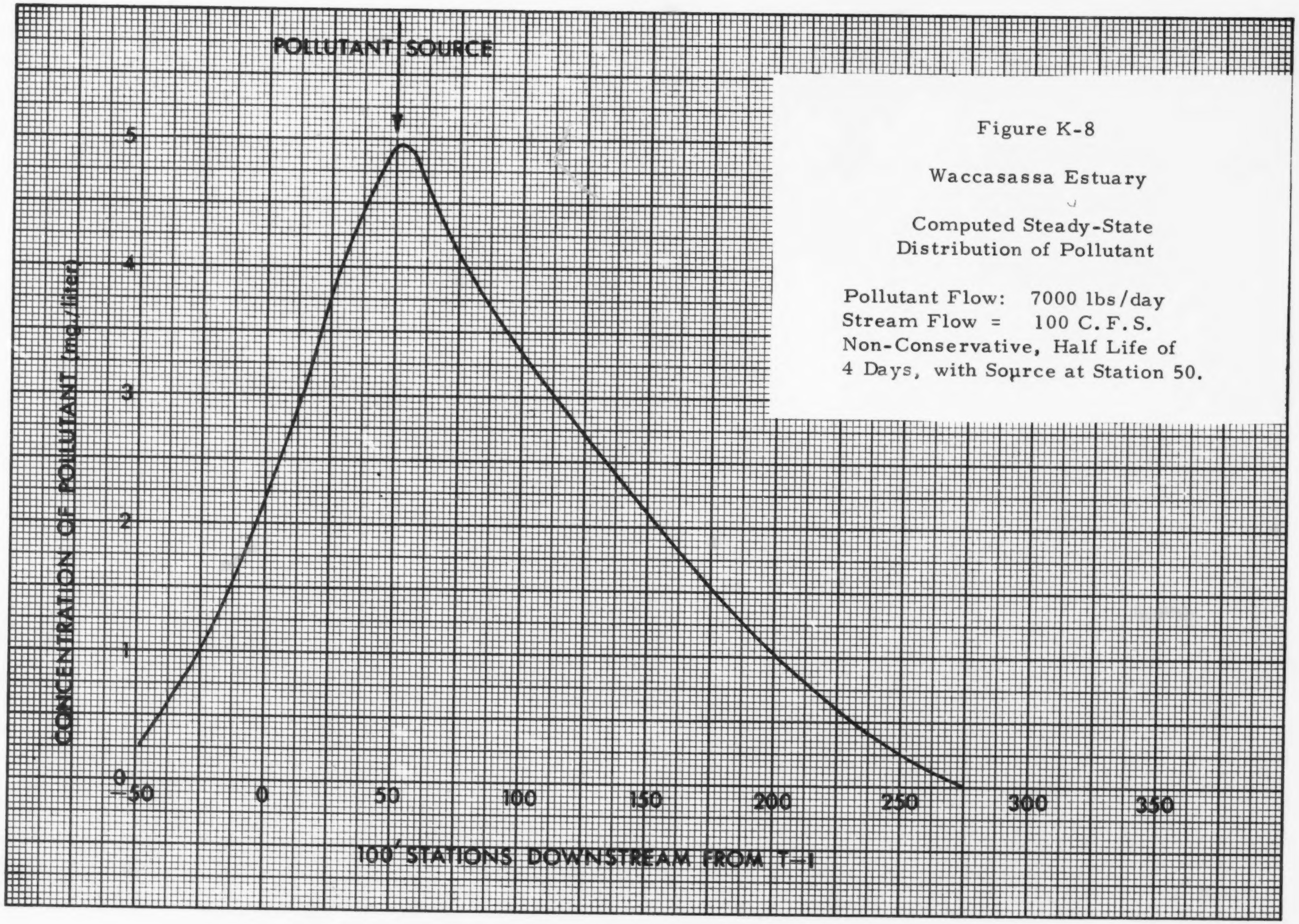


Figure K-8

Waccasassa Estuary

Computed Steady-State
Distribution of Pollutant

Pollutant Flow: 7000 lbs/day
Stream Flow = 100 C. F. S.
Non-Conservative, Half Life of
4 Days, with Source at Station 50.

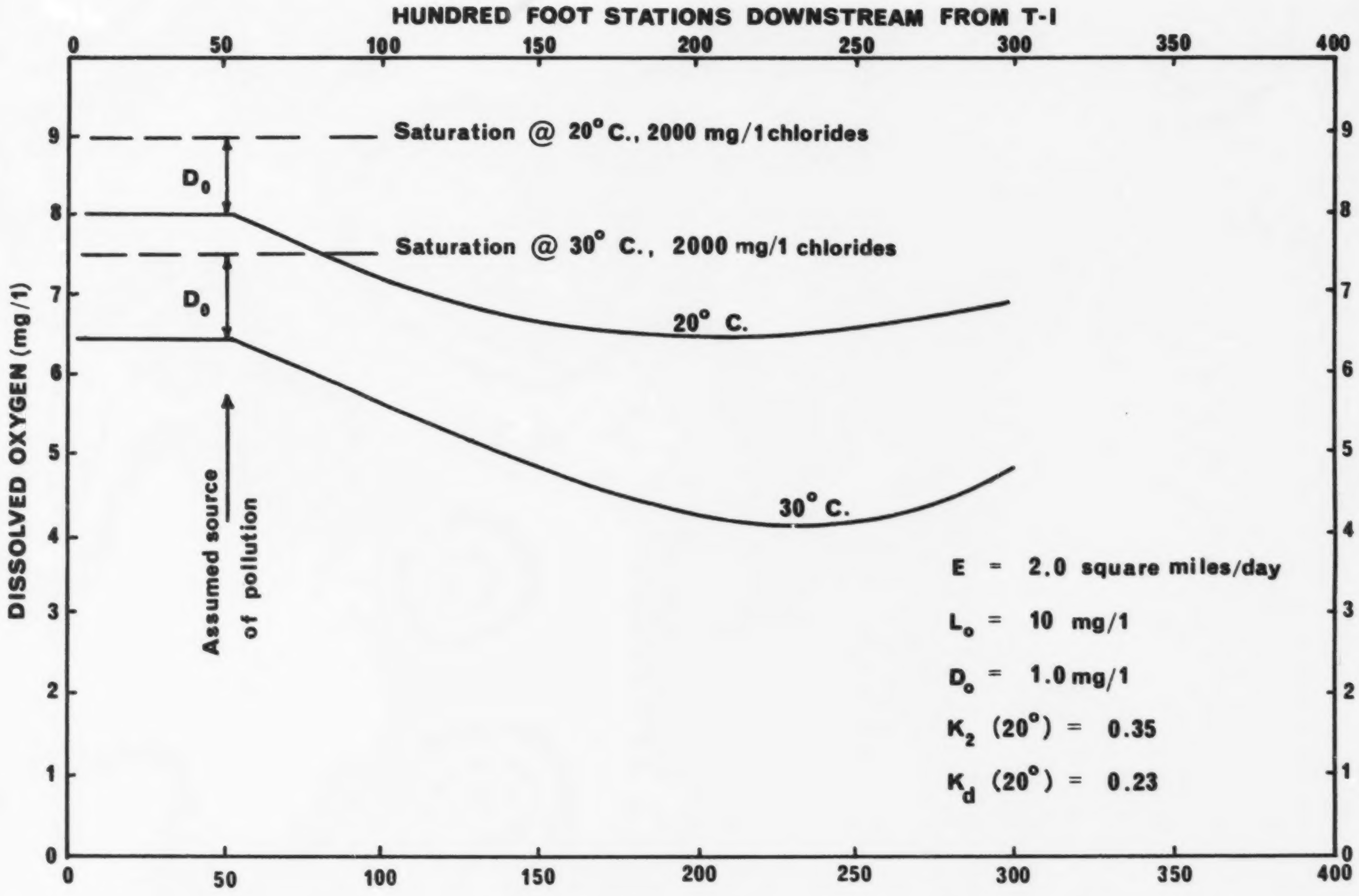


Figure K-9

Waccasassa Estuary

Predicted D.O. Profiles
For 20°C & 30°C

BOD. A dry weather discharge of 100 cfs was assumed, and mean values for net advective velocity and eddy diffusivity were taken as:

U = 0.80 miles per day
E = 2.0 square miles per day

The results of the dissolved oxygen computations are shown on Figure K-9. Saturation values for DO in water having 2000 mg/liter of chlorides are 9.00 mg/liter and 7.50 mg/liter at 20°C and 30°C. The maximum deficit of oxygen at 20°C is 2.50 mg/liter, and this occurs about three miles downstream from the source. At 30°C the maximum deficit is 3.44 mg/liter, and the location is approximately a mile farther out. It should be noted that these are based on steady-state low flow conditions. Any increase in river flow would operate to raise the dissolved oxygen level. The maximum deficit of 3.44 mg/liter still leaves dissolved oxygen of 4 mg/liter or more, and there should be no detrimental effect on the game fishing, which is the principal attraction of this estuary. It appears very unlikely that domestic or industrial pollution on the order of 15,000 pounds of BOD per day will be permitted to be dumped into the Waccasassa in the foreseeable future. The population equivalent of such a load would be 300,000, based on good secondary treatment.

PART II

THE FENHOLLOWAY

FB. GEOMORPHOLOGY AND ECONOMY

Geomorphology

General Description. The Fenholloway River Basin (Figure FB-1) comprises an area of 333 square miles which is bounded on the east and north by the Suwannee River Basin; on the north and west by the Econfina River and Regular Creek Basins; and on the southeast by the Spring Warrior Creek and Steinhatchee River Basins.

The basin and offshore area is comparable physiographically to the Waccasassa River Basin and offshore area. Off the Fenholloway, as off the Waccasassa, the coastal waters are shallow for a long distance and there are oyster reefs. The twelve-foot depth contour (see Plate III) is located approximately six miles off the estuary mouth. There is, however, one important difference as regards the physiography of the two areas. The Waccasassa empties into a distinct embayment and the Fenholloway does not, although the nearshore area off the Fenholloway is partially enclosed by Rock Islands on the west and oyster reefs on the south. The Waccasassa embayment, which is oriented NE-SW, may be likened to a funnel through which wind-driven tides can create a surge. A build-up of wind tides in the Fenholloway Estuary would be significantly lower under similar circumstances than those built up in the Waccasassa Estuary because of the relatively narrow entrance of the Fenholloway. The water levels in both estuaries are affected by winds and the volume of freshwater flow, as well as by astronomical tides as described under E. and FE. TIDAL PHENOMENA.

The littoral area adjacent to the Fenholloway consists of a low tidal marsh backed by higher hammock land and cypress swamps.

The basin relief is mostly level and low lying. The highest parts are in the upper basin near the source of the Fenholloway River where there are some elevations of 100-105 feet above MSL. The land surface slopes gently to the west and southwest. Remnants of Pleistocene bars which were present in the ice age seas may be seen at several locations seven to eight miles inland of the present shoreline.

An artesian ground water head is responsible for the formation of several springs in the middle and lower basin, the combined flow of which does not exceed 15 cfs.

Much of the once heavily wooded higher ground in the basin has been stripped of most of its hardwoods and the swamps have been stripped of virtually all bald cypress. In the swamps now are found pond cypress, cedar, sweet gum, magnolia, and bay trees. Most of the well-drained areas in the basin have been re-forested with slash pine.

Geology and Physiography

All of the Fenholloway Basin is underlain by Suwannee limestone generally covered by a thin mantle of Pleistocene terrace sands. The Suwannee is a yellowish colored limestone and is commonly hard. Residual clay in small solution holes is abundant. As in the base of the Avon Park Series in the Waccasassa Basin, the Suwannee is dolomitized in many places, and at surface exposures frequently all calcium carbonate has been leached from it, leaving flint. Figure FB-2 shows a geological cross section of the basin from the town of Perry, county seat of Taylor County, to the Gulf.

In most of the lower and upper portions of the basin, and particularly in San Pedro Bay, the quartz sand of the marine terraces, in that part through which the water table fluctuates, contains organic matter in its interstices. This type of organic hard pan appears to retard the downward movement of water, creating swampy conditions and facilitating rapid runoff of precipitation under normal ground water level conditions.

The karst topography, which was described in detail in the geological description of the Waccasassa Basin, is also present here. Aerial reconnaissance (Figure A-4) reveals many sinks.

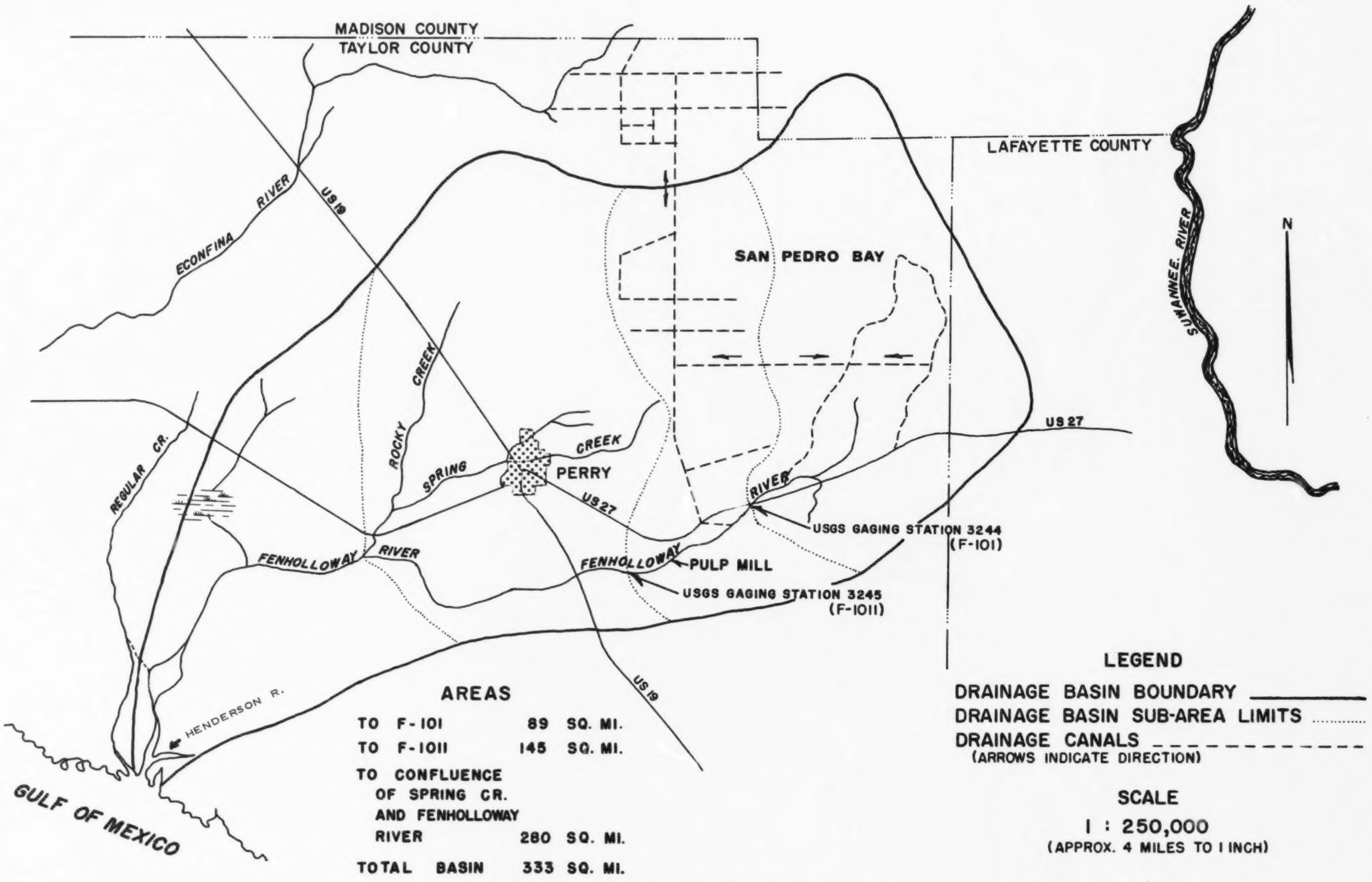

MADISON COUNTY
TAYLOR COUNTY
LAFAYETTE COUNTY
SUWANNEE RIVER
N
ECONFINA RIVER
US 19
SAN PEDRO BAY
ROCKY CREEK
SPRING CREEK
PERRY
US 27
RIVER
USGS GAGING STATION 3244 (F-101)
FENHOLLOWAY RIVER
FENHOLLOWAY
PULP MILL
USGS GAGING STATION 3245 (F-1011)
REGULAR CR.
HENDERSON R.
GULF OF MEXICO
AREAS
TO F-101 89 SQ. MI.
TO F-1011 145 SQ. MI.
TO CONFLUENCE OF SPRING CR. AND FENHOLLOWAY RIVER 280 SQ. MI.
TOTAL BASIN 333 SQ. MI.
LEGEND
DRAINAGE BASIN BOUNDARY
DRAINAGE BASIN SUB-AREA LIMITS
DRAINAGE CANALS
(ARROWS INDICATE DIRECTION)
SCALE
1 : 250,000
(APPROX. 4 MILES TO 1 INCH)

Figure FB-1

Fenholloway River Basin

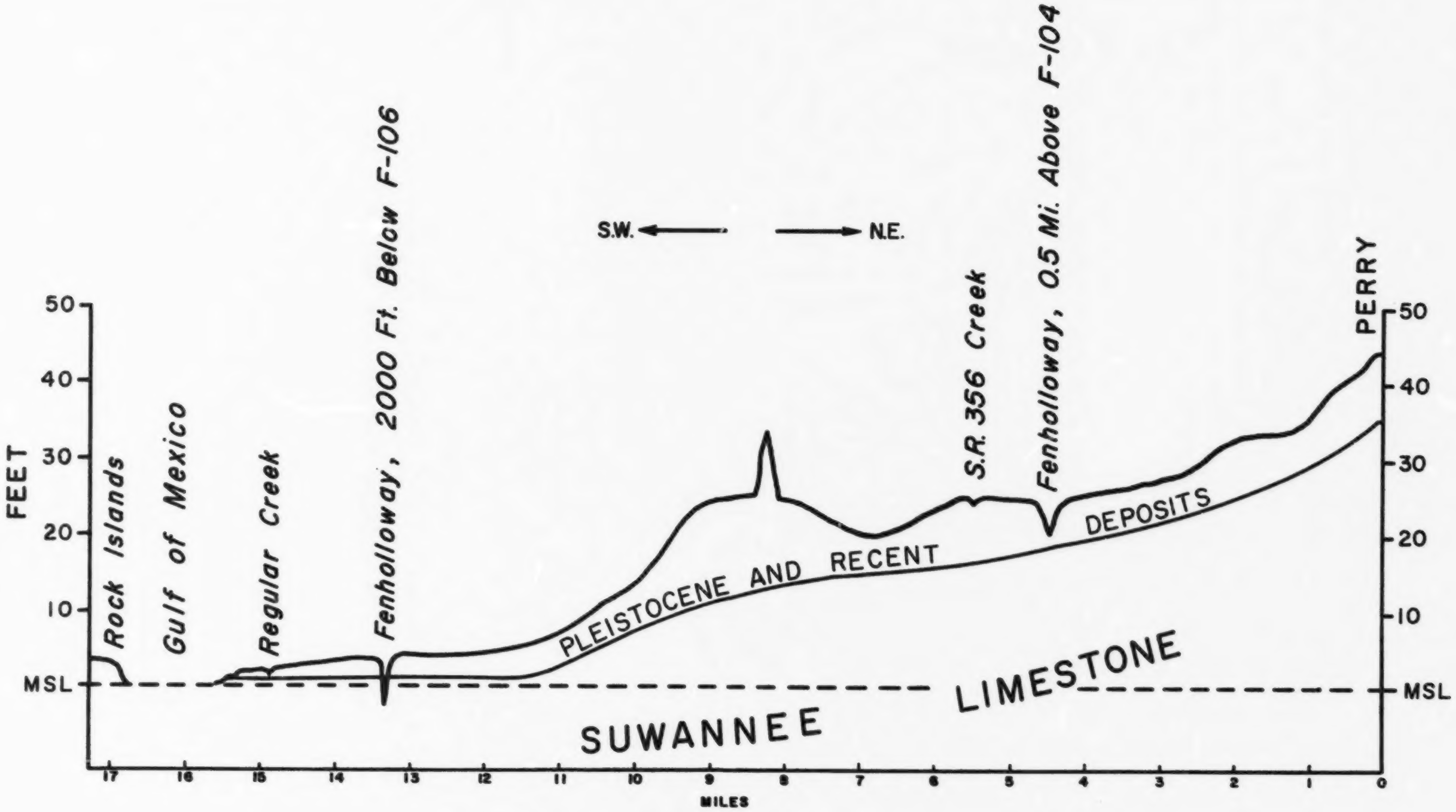


Figure FB-2

Geological Cross-Section
Perry to Gulf of Mexico
(Rock Islands)

The Rivers and Streams

The Fenholloway. The source of the Fenholloway River is in San Pedro Bay (Figure FB-1), a saucer-like recharge and discharge area. It is a mucky covered swamp elevated from 80 to 105 feet above MSL. A large part of this swamp is part of the tree farming acreage of the Buckeye Cellulose Corporation, and because of the company's desire to produce pine trees for pulp wood it has been systematically drained in recent years. This has affected the hydrology of both the Fenholloway Basin and the Econfina Basin adjoining it to the west.

A system of drainage canals has been constructed in the bay. The system is effective in controlling the ground water and draining it to the Fenholloway and Econfina Rivers. Flood waters are diverted through the system away from Spring Creek and Pimple Creek and from the town of Perry, which experienced serious flooding in June, 1957. Flow in the canals is controlled by log-riser gates, the operation of which provides a flushing mechanism for the Buckeye pulp mill wastes which, after lagooning, are emptied into the Fenholloway at Foley. Figure FB-1 shows the location of the canals. Controlled discharge from the canals is made into the Fenholloway before the river flows out of San Pedro Bay, and again approximately three miles upstream from the mill at Foley.

Four named springs are located in the Fenholloway Basin (Figure A-5). These and smaller springs contribute a total flow to the river system of not over 15 cfs.

The Fenholloway is not a sluggish stream. Once it leaves San Pedro Bay it flows approximately 25 miles to the tidal limits of its estuary at an average velocity of about one foot per second during periods of average streamflow. The velocity is a little less than this above the mill and a little more below the mill. A period of approximately 30 hours is required for movement of water from San Pedro Bay to the tidal limits of the estuary located one mile above Station F-106. Table A-2 shows the distances between sampling stations from F-101 to F-1.

The only wholly fresh water tributaries of consequence are the controlled drainage ditch which discharges to the river from the right above the Buckeye mill, and Spring Creek which flows in from the right approximately five miles west of the town of Perry and 7.5 miles above the tidal limits of the estuary. However, during periods of very high flow, two other tributaries downstream from the confluence of Spring Creek can make a considerable contribution of fresh water. These streams are Rocky Creek (not to be confused with the Rocky Creek which is tributary to Spring Creek), the channel of which meets the Fenholloway 4.5 miles below the entry of Spring Creek, and Regular Creek cut-off which enters Thomas Mill Run (right channel of the Fenholloway around Thomas Mill Island) at the tidal limits of the estuary. The Regular Creek cut-off, which is dry except during periods of heavy runoff, may be compared with Dixon Branch in the Waccasassa Basin. There is, however, one very important difference. The Regular Creek cut-off flow comes from outside the Fenholloway drainage area; ~~the Dixon Branch flow comes from outside the Fenholloway drainage area~~; the Dixon Branch flow is intra-area. Two drainage ditches dug for drainage of timberland south of Hampton Springs contribute an average estimated 5-10 cfs to the river's flow.

Spring Creek. The drainage basin of Spring Creek forms a large part of the total drainage basin of the Fenholloway. Its tributaries proceeding downstream are Pimple Creek, Woods Creek, and Rocky Creek, all of which have dendritic source streams in the western part of San Pedro Bay. Both Spring Creek and Woods Creek are sinking creeks – flowing underground through cavernous limestone for a small part of their runs.

Slough and Cut-Off Creeks. Slough Creek which enters the Fenholloway just below Sampling Station F-1061, and Cut-Off Creek, which diverts part of the flow of Slough Creek southward to Henderson River, are both classified as tidal streams (see Inset, Figure A-5). The fresh water flow of both creeks is negligible.

Henderson River. The source of Henderson River is in hammock land in the eastern part of the Fenholloway Basin about three miles east of its confluence with the Fenholloway. This is a tidal stream that at first glance may be compared with Cow Creek in the Waccasassa Basin. It is, however, a much smaller stream as measured by cross sections and fresh water flow. The cross-channeled marsh of the lower Fenholloway Basin is responsible for a confused ebb and flood regime in Henderson River. Near Sampling Station F-109 two branches of East Cut-Off Creek (the first estuary east of the Fenholloway as shown in Figure A-5) flow into and out of Henderson River, depending upon the tidal stage.

The Coast

As in the case of the Waccasassa, the coastline bordering the study area forms a part of the tidal marsh littoral zone that extends from a landward point opposite Anclote Keys on the south to Apalachee Bay on the northwest. There is, however, more sand in the offshore area and there are several small sand beaches 15-20 miles southeast of the Fenholloway.

Some sediment but virtually no sand is carried to the coast by the streams in the Fenholloway area. This was characteristic of the Waccasassa also. The offshore area is underlain at shallow depth by limestone forming a broad, shallow bank. Any substantial wave energy is dissipated well offshore. This permits the sediments reaching the coast by way of the stream to be deposited and the tidal marsh to prograde.

Oyster reefs, now dead, are found off the mouth of the Fenholloway as shown on Plate III. These reefs are exposed at low water, and in conjunction with Rock Islands to the west, form a partially enclosed lagoon.

The entrance of the Fenholloway Estuary, although smaller than the Waccasassa funnel, is similar in origin. Both are drowned valleys with their rapidly widening cross sections resulting from confluences, and both apparently eroded into recent sediments as the result of tidal scour at a time when the offshore oyster reefs offered less obstruction to the river entrances.

Soils

Most of the soils in the Fenholloway Basin were developed by the sandy deposits overlying the calcareous formations, and major distinctions in classification are derived from drainage conditions. The coastal area landward of the marsh and in the area in San Pedro Bay have gray to black poorly-drained acid soils. In most places they overlay brown organic hard-pan and light gray subsoils. These soils are known for their pine and scrub palmetto flatwoods.

The soils in the middle section of the basin which extend in all directions a maximum distance of about 12 miles from the town of Perry are in most cases well-drained noncalcareous sands having loose sandy subsoils. In places they support a native vegetation of long leaf pine and blackjack oak. Although inherently low in plant nutrients, these soils for the most part are good for general farm crops – corn, tobacco, potatoes, field peas, velvet beans, and forage crops. The blackjack lands are suitable for growing pecans and blackberries.

Weather and Climate

The estimated long-term basin average for precipitation is 74.88 inches as described under FD. HYDROLOGY, and is heaviest during June, July, and August. Temperatures average approximately 81° in August and 56° in January.

Hurricane records in the basin are poor. The most recent hurricane was Dora, which occurred in September, 1964. This storm is described under FD. HYDROLOGY and FE. TIDAL PHENOMENA.

Resources

Land. The Fenholloway Basin comprises approximately 213,000 acres. The density of population is greater here than in the Waccasassa Basin, but still quite low – an average of 21 acres for each resident. Out of a total land area of 652,300 acres in Taylor County, forest land accounts for 589,300 acres, or 90.3 per cent. Out of 213,000 acres in the river basin there are approximately 170,000 acres in forest land; 10,000 acres in urban land; 20,000 acres in farm land and pasture land; and 13,000 acres in marsh and swamp land.

Water. The Fenholloway Basin has an adequate supply of good quality water from ground water sources. The Floridan aquifer underlies all of the drainage basin, as it does the majority of the drainage basins in the State of Florida. This artesian aquifer consists of limestone formations averaging several hundreds of feet in thickness.

In the middle basin the Fenholloway River is connected hydrologically with the aquifer, and several springs discharge into the river system as described above. The entire basin is primarily a discharge area; the artesian heads ranging from about 50 feet in the San Pedro Bay area (source of the Fenholloway River) to near sea level at the mouth of the Fenholloway.

In primary recharge areas, the water level in the Floridan aquifer may represent the water table, but in the case of the Fenholloway Basin, a discharge area, there is a separate water table aquifer above the piezometric surface of the artesian water.

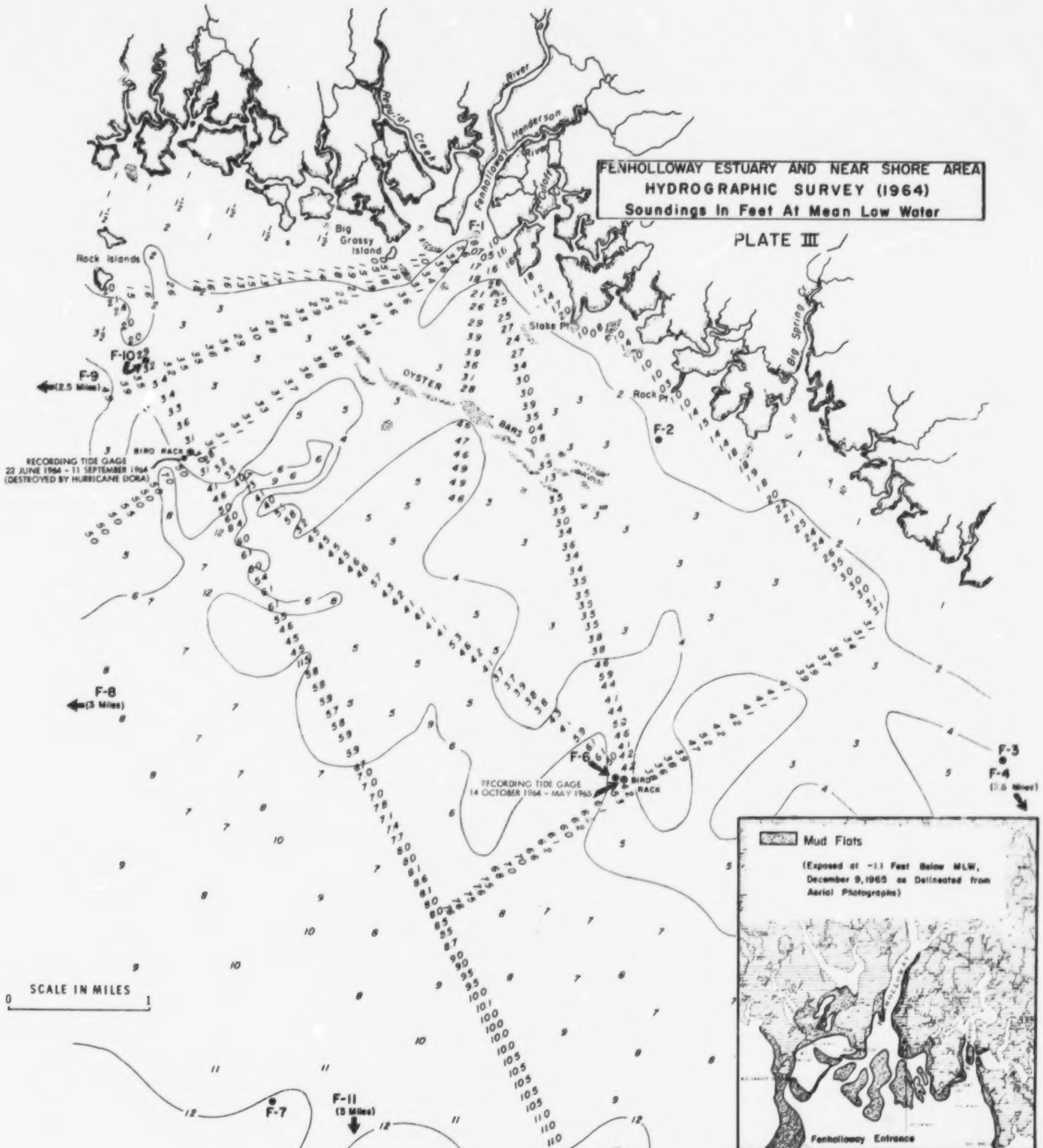
Pollution is a serious problem in the basin. Industrial wastes and untreated sewage are emptied into the Fenholloway above Sampling Station F-1011, and raw domestic wastes are discharged into the river below Sampling Station F-102 as described under FH. SANITARY SURVEY.

Cultural and Economic Characteristics

Historical Background. Taylor County was created in 1856. The population of the county in 1860 was 1384 and 2279 in 1880. Several railroads extended their lines to Perry between 1902 and 1907, resulting in a considerable increase in population. The incentive for the railroad building was the vast naval stores and lumber potential.

Population. The population of the Fenholloway Basin, though small, increased steadily from the time of the opening of the territory, and particularly with Florida's statehood in 1845, until World War II, by which time the supply of marketable saw timber and naval stores was becoming exhausted. As a result, the population decreased between 1940 and 1950.

The most marked increase in population in the Fenholloway Basin, and particularly in and around the town of Perry, took place as the result of the establishment of the Buckeye Cellulose mill at Foley (four miles southeast of Perry) in 1954. In 1950 Perry had an unofficial population of 2279. According to the United States census



FENHOLLOWAY ESTUARY AND NEAR SHORE AREA
HYDROGRAPHIC SURVEY (1964)
Soundings In Feet At Mean Low Water

PLATE III

Fenholloway River
Henderson River
Spring Creek
Big Grassy Island
Rock Islands
Stake Pt.
Rock Pt.
Big Spring
OYSTER BARS
BIRD ROCK
RECORDING TIDE GAGE 22 JUNE 1964 - 11 SEPTEMBER 1964 (DESTROYED BY HURRICANE DORA)
RECORDING TIDE GAGE 14 OCTOBER 1964 - MAY 1965
F-1
F-2
F-3
F-4 (2.5 Miles)
F-5
F-6
F-7
F-8 (3 Miles)
F-9 (2.5 Miles)
F-10
F-11 (3 Miles)
SCALE IN MILES
0
1
Mud Flats
(Exposed at -1.1 Feet Below MLW, December 9, 1965 as Delineated from Aerial Photographs)
Fenholloway Entrance

this had increased to 8330 by 1960. The 1960 official census of Taylor County listed a population of 13,200.

Social and Institutional Factors. Taylor County has a fully accredited school system with a school population of approximately 3000. In addition, the county cooperates with neighboring counties in the operation of the North Florida Junior College located at Madison. The county is served by a new and modern thirty-one bed hospital.

Existing Economy. The economy of the Fenholloway Basin is based almost entirely on forest products. Agriculture assumes a minor role, as does fishing and manufacturing. Income from tourists passing through the Perry area on various federal highways increased rapidly from 1954 until the completion of Interstate 75. A large number of motels were built, and even though many showed a loss during 1965, it is expected that their economy will stabilize after the completion of the four-laning of U. S. Highway 19 to St. Petersburg.

Out of the total (approximate) 1963 labor force in the Perry-Foley area of 1709, the industries producing wood and wood products employed 1227 or 72 per cent of the total. Of the 1227, the Buckeye Cellulose Corporation employed 755.

In 1959, with the completion of a new $20,000,000 mill, the Buckeye Cellulose Corporation doubled the original capacity of its wood pulp operations which were established at Foley in 1954. The new capacity, which is once again in the process of being increased by 33,000 tons, is 200,000 tons of dissolving pulp, or 266,000 tons of paper pulp a year. The new mill is integrated with the original mill in a semi-independent tandem arrangement. Both are linked department by department, but either can be operated independently of the other at all times if desired. Both mills can run one grade of pulp or different pulps, dissolving pulp, or a high grade of bleached pulp.

Expansion of the Buckeye facilities required an increase in wood consumption from 750 cords a day in 1954 to 1400 cords a day in 1960. Although the company's land holdings now total more than 800,000 acres (1965) – one of the largest forest acreage-to-productive-capacity ratios in the pulp and paper industry – most of the wood used at Foley is secured from sources other than the company's forests.

The second largest employer in the Perry area, with a total of 115 employees in 1963, was the Lee-Tidewater Cypress Company. The products of this concern, one of the world's largest cypress sawmills, are red cypress lumber, crates, and boxes.

One employer of consequence not dependent upon the products of the forest is the Metcalf Crab Company, whose plant is located on Spring Creek south of Sampling Station F-103. The company cans crab meat for northern markets. About 6500 pounds are shipped each week. Crabs are trapped up to a distance of about ten miles offshore from the Fenholloway entrance. The crab company operates its own boats out of the Fenholloway and also makes purchase from independent crabbers.

Economic Potential – Future Outlook. The potential of the Fenholloway Basin is geared chiefly to the production of products of the forest, principally cellulose. Agriculture is restricted because of soil conditions. Tourists contributing to the motel economy should increase as the total number of travelers to the State of Florida increases.

Crabbing and fishing in the waters offshore from the basin are unlikely to become more important in the foreseeable future. Recreational hunting and fishing in the basin, and particularly in those parts of the basin that are a part of the Aucilla Wildlife Management Area, will continue to be attractive to the local people but of little importance as far as the tourist trade is concerned.

The completion of the intracoastal waterway from the eastern terminus of the Gulf Intracoastal Waterway in Northwest Florida to the western terminus of the Cross-State Barge Canal (Withlacoochee River entrance) could, if achieved, have an effect on the littoral zone in the Fenholloway area similar to the effect which might be experienced in the Waccasassa area (see Section B). Such low cost water transportation could also be an incentive for expanded development of pulping as well as increased production of cellulose and pulp in the Fenholloway Basin.

FC. HYDROGRAPHY

A hydrographic survey of the Fenholloway River, Estuary, and offshore area was conducted during the period July-September, 1964. Because the Fenholloway Estuary is narrower and its offshore area shallower than the Waccasassa, it was not feasible to use echo-sounding equipment as in the Waccasassa survey. Aluminum staffs graduated in feet and tenths of feet were used in nearly all of the work. On occasion it was necessary to use a lead line to sound the bottoms of some solution holes.

The survey consisted of some 30 cross sections and longitudinal profiles of the Fenholloway Estuary and offshore area, including the tributary estuary of Henderson River. The location of these sections is shown on Plate III and Figure FC-1. Typical sections are shown on Figures FC-2 and FC-3.

Some of the similarities, as well as dissimilarities, of the hydrography of the Fenholloway and Waccasassa areas have been discussed under FB. GEOMORPHOLOGY. In describing the hydrography of the Waccasassa Estuary, reference was made to the natural estuary channels which were drainage channels cut in the limestone plain before that region was submerged by a rise in sea level. These channels are clearly shown on the aerial photographs of

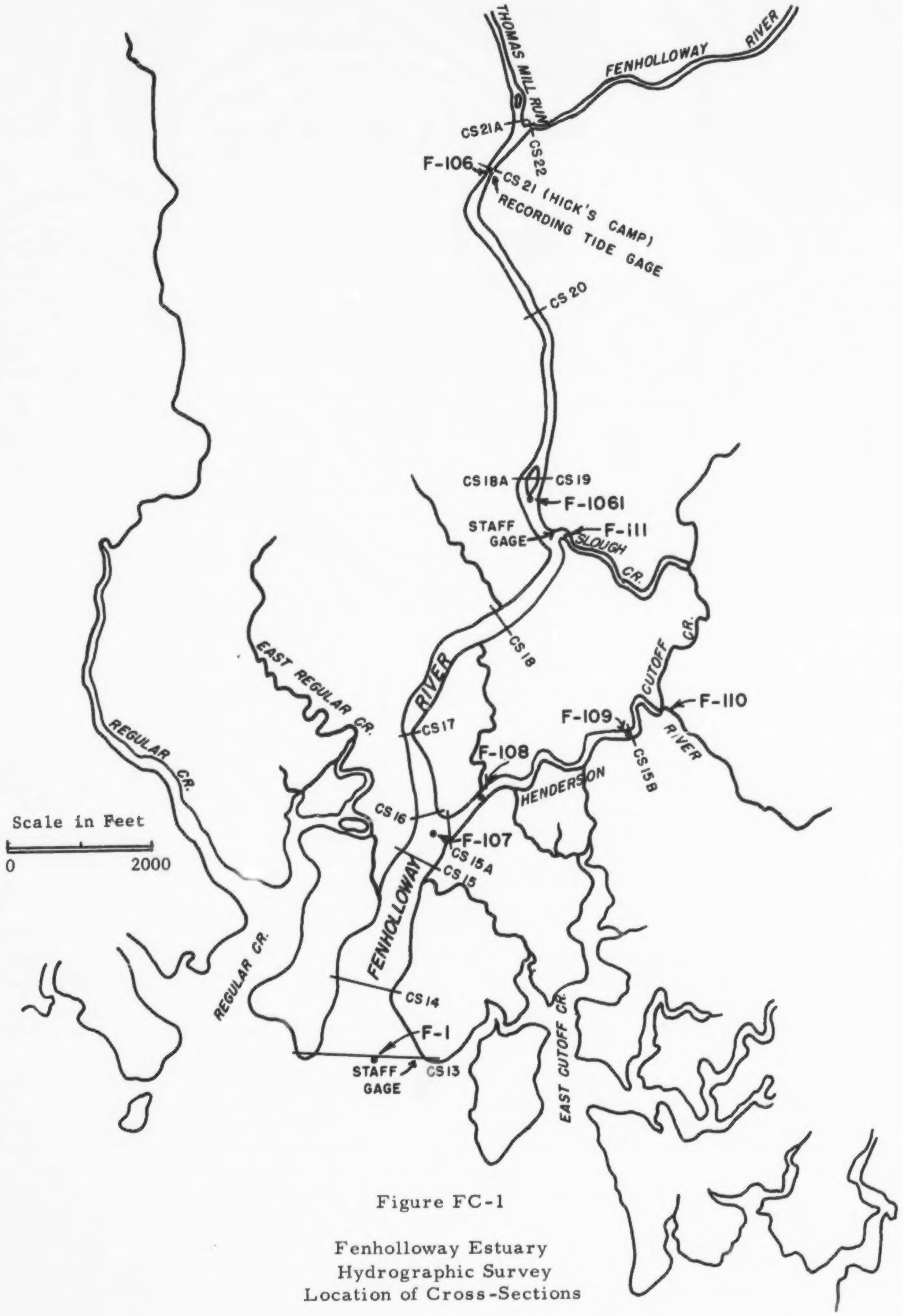
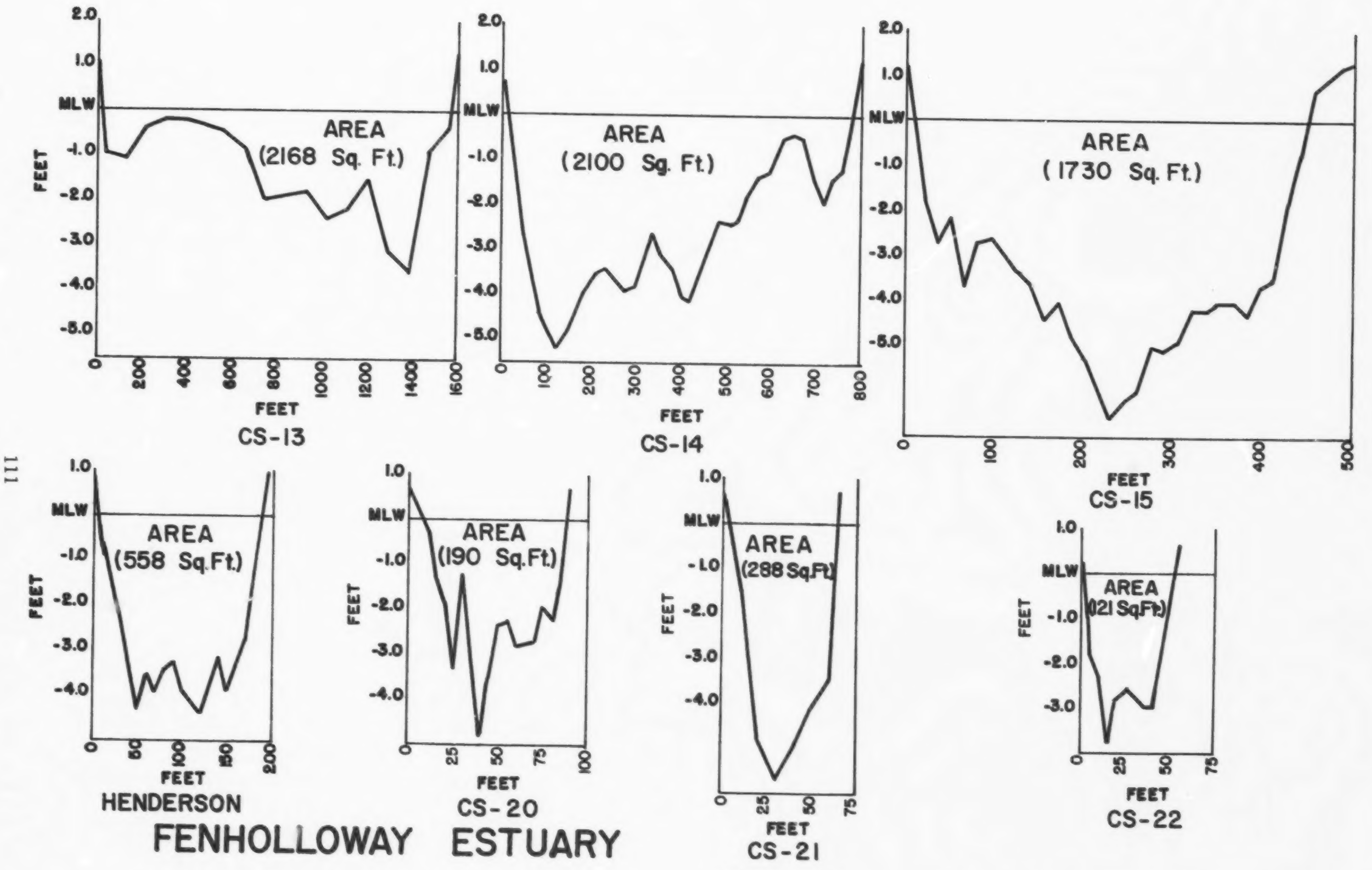

THOMAS MILL RUN
FENHOLLOWAY RIVER
CS21A
CS22
F-106
CS 21 (HICK'S CAMP)
RECORDING TIDE GAGE
CS 20
CS18A
CS19
F-1061
STAFF GAGE
F-111
SLOUGH CR.
CS18
CUTOFF CR.
F-110
F-109
RIVER
EAST REGULAR CR.
RIVER
CS17
F-108
HENDERSON
CS15B
REGULAR CR.
Scale in Feet
0
2000
CS16
F-107
CS15A
CS15
FENHOLLOWAY
REGULAR CR.
CS14
F-1
STAFF GAGE
CS13
EAST CUTOFF CR.

Figure FC-1

Fenholloway Estuary
Hydrographic Survey
Location of Cross-Sections



NOTE: Refer to Figure C-1 for cross section locations.

Figure FC-2

HYDROGRAPHIC SURVEY

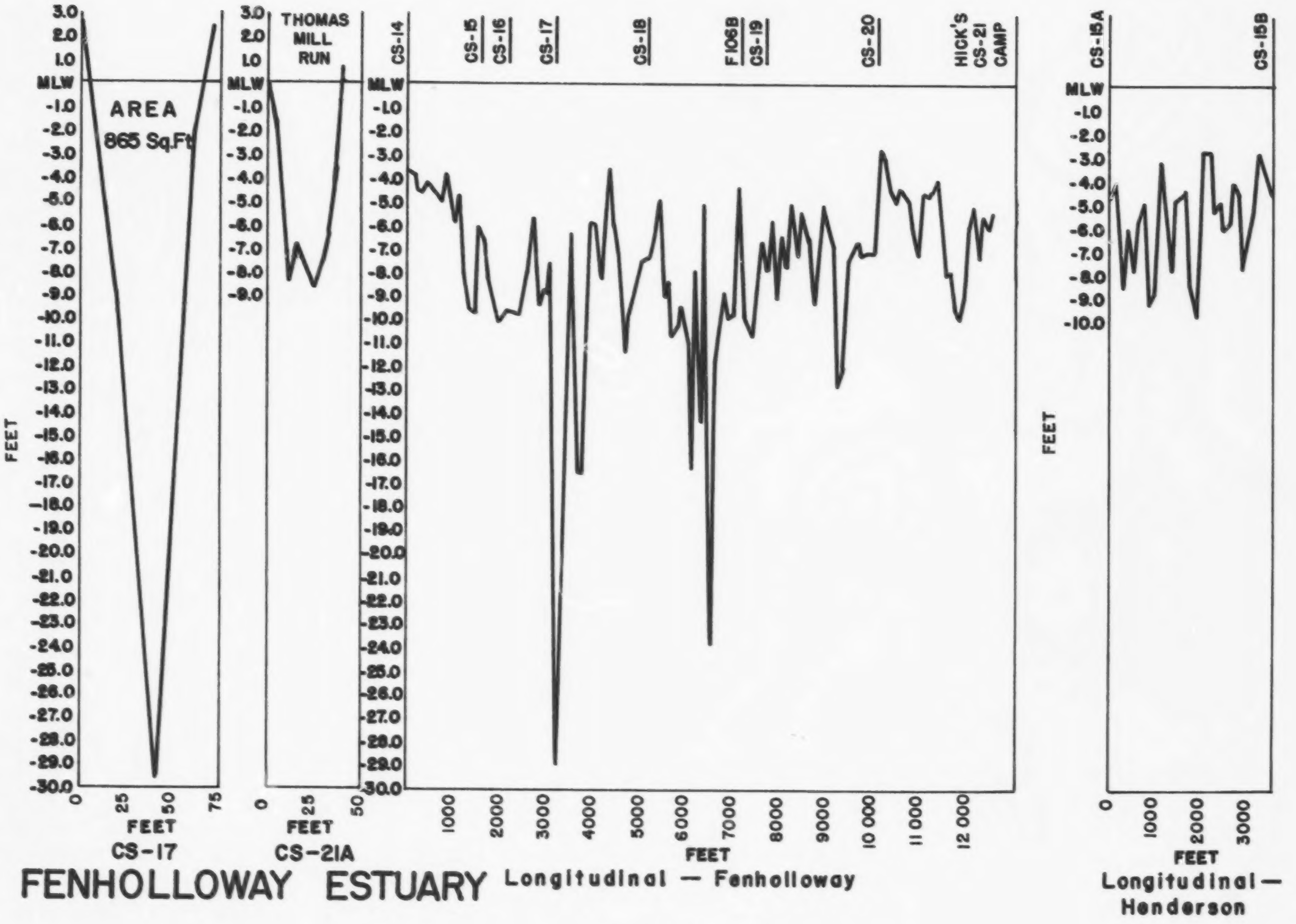


Figure FC-3
HYDROGRAPHIC SURVEY

the area (Figure A-1). One might surmise that comparable channel conditions would be found in the Fenholloway Estuary but such is not the case. The mouth of the Fenholloway Estuary is narrower than the Waccasassa, and it is located on a straight, open coast line whereas the Waccasassa flows into a funnel-shaped bay. These factors precluded the cutting of distinct ebb and flood channels in the Fenholloway. Other factors have had a bearing on the difference in nearshore bottom topography in the two estuaries. Oyster reefs were formed much closer to the entrance of the Fenholloway River than to the entrance of the Waccasassa River. These reefs and the resultant silting shallowed the nearshore Fenholloway entrance to such an extent that navigation at low water is impossible in all but very shallow draft boats (see Plate III Inset). The oyster reef formations off the Fenholloway Estuary have remained essentially the same for many years. The reefs were "alive" prior to 1954 when the Fenholloway became an industrial stream.

The inside cross sections which may be located on Figure FC-1 and which are depicted on Figures FC-2 and FC-3 generally increase in area progressively from CS 22 above Station F-106 to the Gulf. CS 17 is a deep solution hole comparable to those found in the Waccasassa Estuary.

FD. HYDROLOGY

A general description of the Fenholloway Basin is presented under FB. GEOMORPHOLOGY and FC. HYDROGRAPHY, including the drainage pattern, physiography, soils, geology, and other physical characteristics. Figures A-4, A-5, and FC-1 show various features of the estuary and tributary drainage area. The estuary and tidal river extend from Station F-1 at the mouth to about a mile above Station F-106 at Hicks Camp, a distance of some 3.8 miles. The head of the estuary is taken as at Station F-106 where there is a mean tidal range of 1.9 feet. At this station, chlorides average around 20 mg/l but may go to 1000 mg/l under certain conditions of wind and tide. There are no stream gaging stations in the tidal river, and estimates of fresh water contribution have to be made from stations several miles upstream. Both rainfall and streamflow characteristics are reviewed in this section.

Rainfall

No long-term rainfall records exist within the drainage area other than that at Perry. Unfortunately this is not considered a reliable record for long-term analytical purposes. There are four Forest Service fire tower stations (hereafter called tower stations) well distributed within the drainage area as indicated on Figure A-5. The records from these stations began in 1959. Monthly averages for the 1959-63 period were computed for a number of long-term stations nearest the drainage area. The Cross City record resembled most closely in the general characteristics of monthly distribution that for the tower stations, as indicated on Figure FD-1 Hence, by applying the percentage variation of the five-year 1959-63 averages from the long-term monthly averages at Cross City to the five-year 1959-63 averages at the tower stations, a synthetic long-term record for the tower stations was derived. This also is shown on Figure FD-1. The seasonal character of the rainfall is evident. It is believed that the synthetic long-term monthly averages for the tower stations as shown in Table FD-1 are reasonably close to actual values. From them have been calculated the estimated monthly excess or deficiency of precipitation on the drainage area as shown also in Table FD-1 for the period of the study. The latter data have been plotted on Figure FD-2.

The synthetic long-term record for the tower stations is based on the five-year period 1959-63 rather than the seven-year period 1959-65 for two reasons: (a) to compare with the records used in the Waccasassa study, and (b) because the 1959 and 1964 annual rainfalls were the second and third highest in 20 years and produce a seven-year average unduly high to compare with the long-term average at Cross City.

The synthetic long-term annual average of 74.88 inches for the tower stations is 17 to 23 inches greater than at the long-term stations mentioned previously. This considerably greater estimated rainfall for the tower stations may seem unreasonable. However, the actual measured 1959-63 annual average for the tower stations is 71.68 as compared with 52.53 inches for the three best located long-term stations, a difference of some 19 inches more for the tower stations. A similar situation existed on the Waccasassa. It appears from these data that a belt of high rainfall exists inland from the coast in these areas. A more extended study of this apparent phenomenon would seem desirable for those concerned with the climatology or hydrology of Florida.

The monthly rainfall at each of the four tower stations is generally quite comparable, except in the wet season from July to September when thunderstorm and hurricane rainfall produce large local differences. The very low rainfall in October, 1963, and May, 1965, was reflected in low streamflow and reduced dilution of wastes in the river.

The year 1964 was the second highest rainfall year of record, and this naturally affected streamflow as described subsequently. From Table FD-1 it will be noted that extremely heavy rainfall occurred in July and September. The September rainfall was the greatest of record for that month, and was due chiefly to Hurricane Dora.

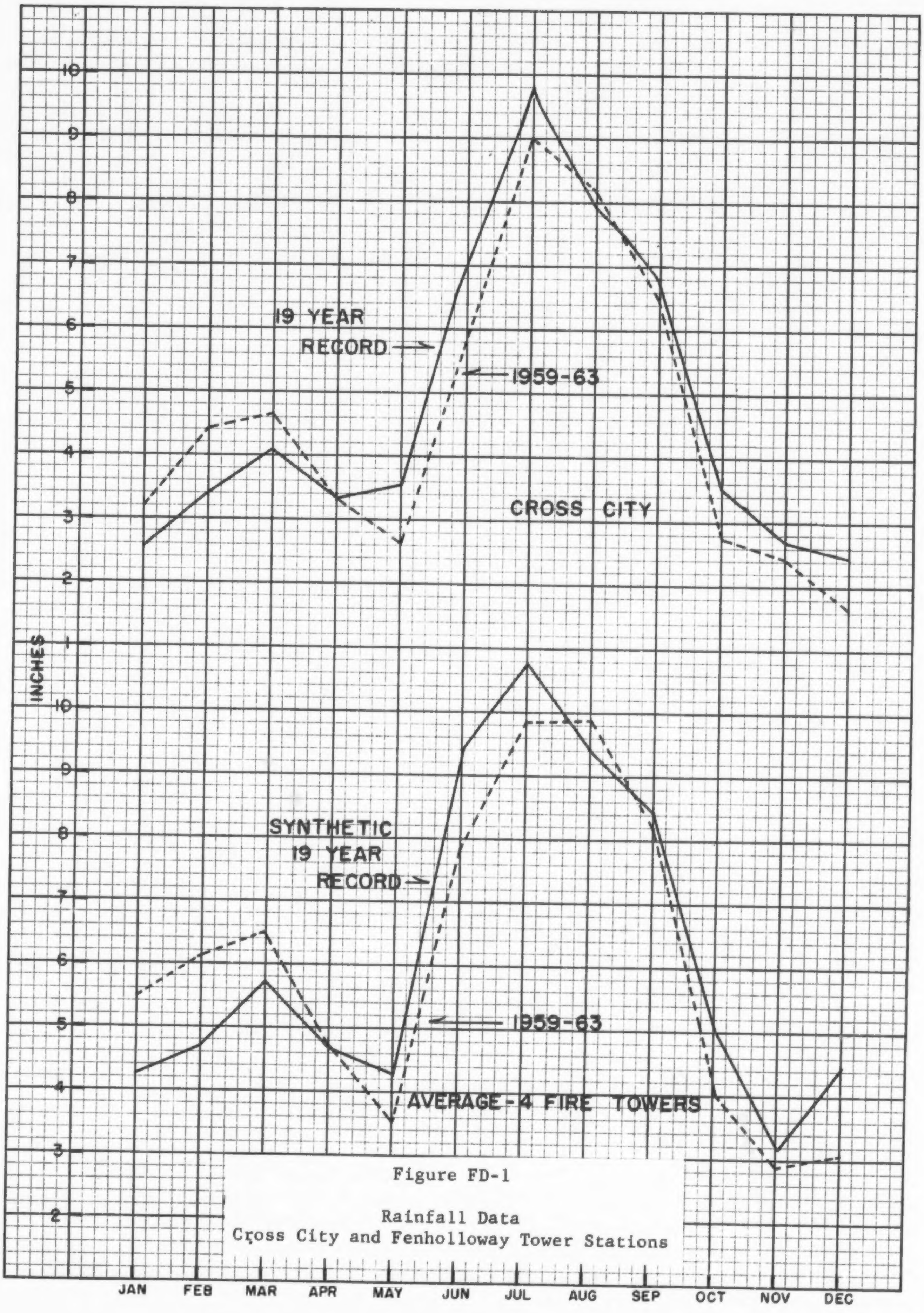


Figure FD-1

Rainfall Data
Cross City and Fenholloway Tower Stations

Table FD-1

AVERAGE PRECIPITATION ON FENHOLLOWAY DRAINAGE BASIN WITH MONTHLY AND ANNUAL DEPARTURES

A. Synthetic Long Term Averages

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
4.34	4.72	5.68	4.72	4.37	9.60	10.75	9.44	8.44	5.02	3.22	4.58	74.88

B. Monthly Precipitation and Departures from Average at Tower Stations During Period of Investigation

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1963	7.78	7.42	1.22	2.45	3.20	9.68	9.02	6.12	5.58	0.18	3.92	4.55	61.12
Dep.	+3.44	+2.70	-4.46	-2.27	-1.17	+0.08	-1.73	-3.32	-2.86	-4.84	+0.70	-0.03	-13.76
1964	12.15	9.88	3.70	10.85	1.82	8.72	11.40	10.55	12.68	4.08	2.96	6.06	94.85
Dep.	+7.81	+5.16	-1.98	+6.13	-2.55	-0.88	+0.65	+1.11	+4.24	-0.94	-0.26	+1.48	+19.97
1965	2.65	3.76	6.60	5.74	0.27	13.20*	9.65						
Dep.	-1.69	-0.92	+0.92	+1.02	-4.10	+3.60	-1.10						

*Average of three stations.

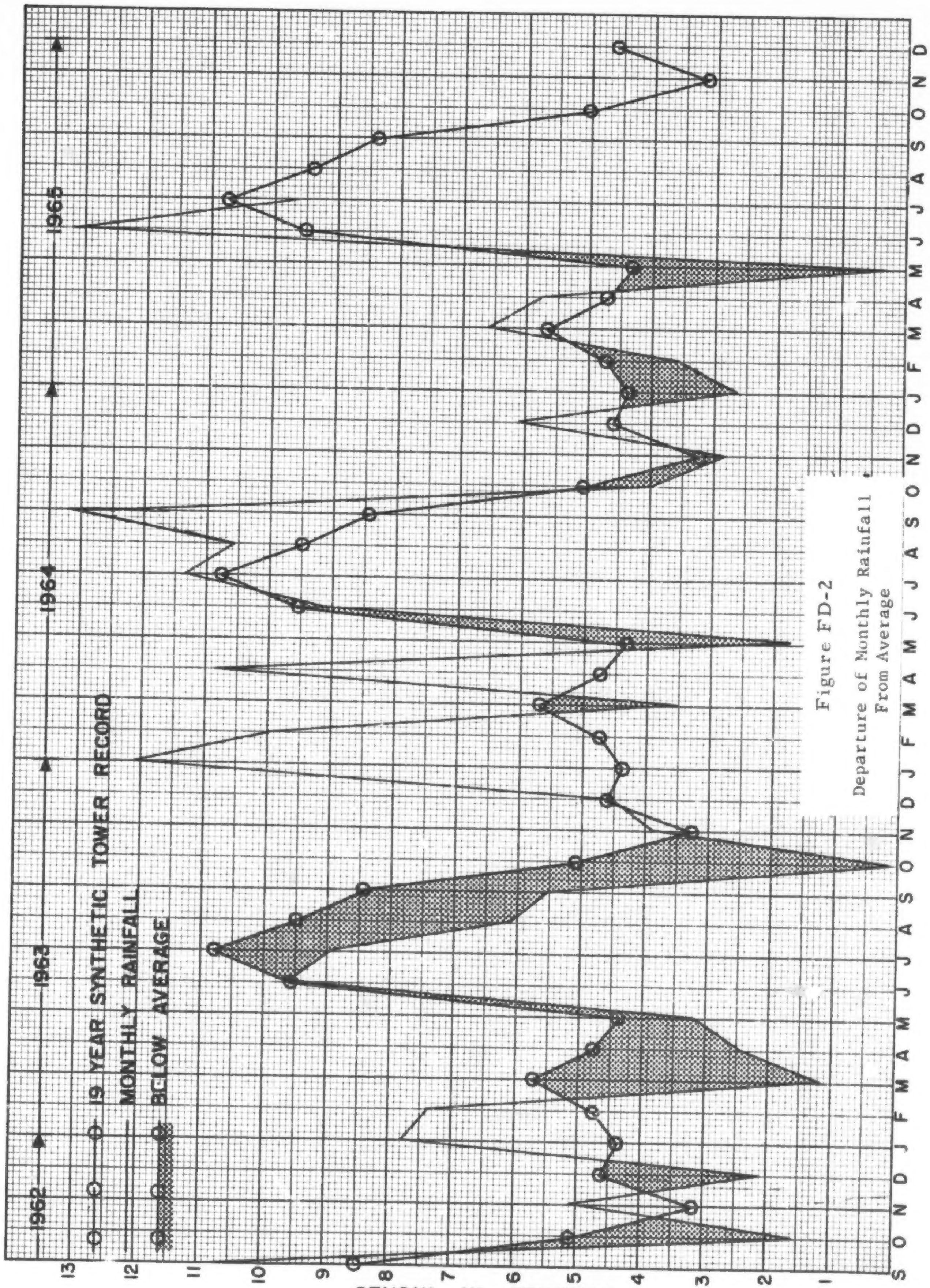


Figure FD-2
Departure of Monthly Rainfall
From Average

Figure FD-2 shows the actual monthly rainfall compared with the synthetic long-term average. It will be noted that 1963 (when most of the work on the Waccasassa was performed) was a very dry year, and that 1964 (when most of the work on the Fenholloway was performed) was a very wet year. In 1964 the total rainfall was 94.85 inches, or 20 inches in excess of the average. Attention is called to the heavy rainfall in January, July, August, and September of 1964 and in June of 1965, which produced flood conditions in the Fenholloway severely interfering with field work and creating abnormal fresh water flow.

Hurricane Dora

On September 10, 1964, Hurricane Dora moved in from the Atlantic in the vicinity of St. Augustine. It was the first hurricane to pass over the northern Florida peninsula from the Atlantic since records have been kept. Its path is shown on Figure FD-3. The center passed westward along the 30th parallel of latitude to a point about eight miles south of Perry. It then curved to the northwest, passing across the Fenholloway near Hampton Springs. Moving northwest and north to the vicinity of Dothan, Alabama, it recurved and moved in an easterly direction across Georgia to the Atlantic Coast. It produced about 12 inches of rainfall on the Fenholloway drainage area during the three days September 10-12 inclusive. The heaviest 24-hour rainfall on the drainage basin was 10.50 inches on September 11 at the Foley Fire Tower Station on the upper part of the river.

Rainfall and runoff data for the Fenholloway during the passage of Hurricane Dora are given in Table D-5 under D. HYDROLOGY for the Waccasassa. The effects of a hurricane surge on September 10 and 11 at Station F-106 near the head of the Fenholloway Estuary are evident as shown on Figure FE-3 under FE. TIDAL PHENOMENA. A similar situation to that described in detail for the Waccasassa undoubtedly existed, but no analysis of the effects on fresh water contribution to the estuary has been made, since no streamflow station with recorder was located near enough to the head of the estuary to make satisfactory estimates of runoff under such extreme conditions. Also, no wind velocity records exist which are applicable to the Fenholloway. However, virtual elimination of tidal variations persisted at Station F-106 until September 17, due to runoff from storage on the headwaters. The effect of upstream storage was more pronounced than on the Waccasassa. Gage height at Station F-106 reached a peak on September 11, then declined nearly two feet by September 13, and then increased and remained virtually steady for three days as water from upstream storage, particularly from San Pedro Bay, reached the head of the estuary.

The hurricane surge plus flood runoff created a storm tide some 4.5 feet above the normal high tide stage at Station F-106, where a tide recorder was located. However, the fact that the storm center passed over the estuary may well have produced larger relative changes in the direction of flow than was the case on the Waccasassa. It should be noted in Table D-5 that the daily flow shown for the Waccasassa represents the net flow indicated by a streamflow recorder equipped with a flow direction device, whereas the daily flow on the Fenholloway is based on the record from the streamflow recorder at Station F-101, located well upstream from any effects of hurricane surge.

The foregoing inferences as to hurricane effects upon the Fenholloway Estuary are based largely on two tide recorders established for the study and described under FE. TIDAL PHENOMENA. One in the Gulf off the mouth of the estuary was torn loose on September 11, and the other near the head of the estuary at Station F-106 operated throughout the storm. The more satisfactory analysis of storm effects described for the Waccasassa points up the desirability of adequate instrumental installations to measure wind, tide, and streamflow in connection with estuarine studies.

Streamflow

There are two U. S. Geological Survey stream gaging stations on the upper Fenholloway River (1). The uppermost is designated on Figure A-5 as Sampling Station F-101 and has a tributary drainage area of about 90 square miles. The other station is located at Sampling Station F-1011. This station is on the Fenholloway immediately below a canal from which waste water from the Buckeye Cellulose Corporation is discharged to the river. The mill takes large amounts of water from wells for cooling and process use. The tributary drainage area at Station F-1011 is about 145 square miles.

No relation could be discovered between the unit flow (cubic feet per second per square mile) at Station F-101 and that at Station F-1011. Not only does the discharge from ground water used by the Buckeye plant, alleged to be a fairly constant 50 million gallons per day (78 cfs), appear to vary in quantity, but the system of canals installed by the Buckeye Corporation on its properties draining to the river above Station F-1011 are operated for both drainage and irrigation purposes. The discharge from these canals is regulated to suit the silviculture operations of the corporation. For these reasons, discharge at Station F-1011 has not been utilized to prognosticate fresh water contribution to the estuary, although it has been used to compute average dilution of wastes which enter the river at that point. The situation briefly mentioned here is described under FB. GEOMORPHOLOGY, Rivers and Streams.

The base station for estimating streamflow on the Fenholloway in connection with this study is the U. S.

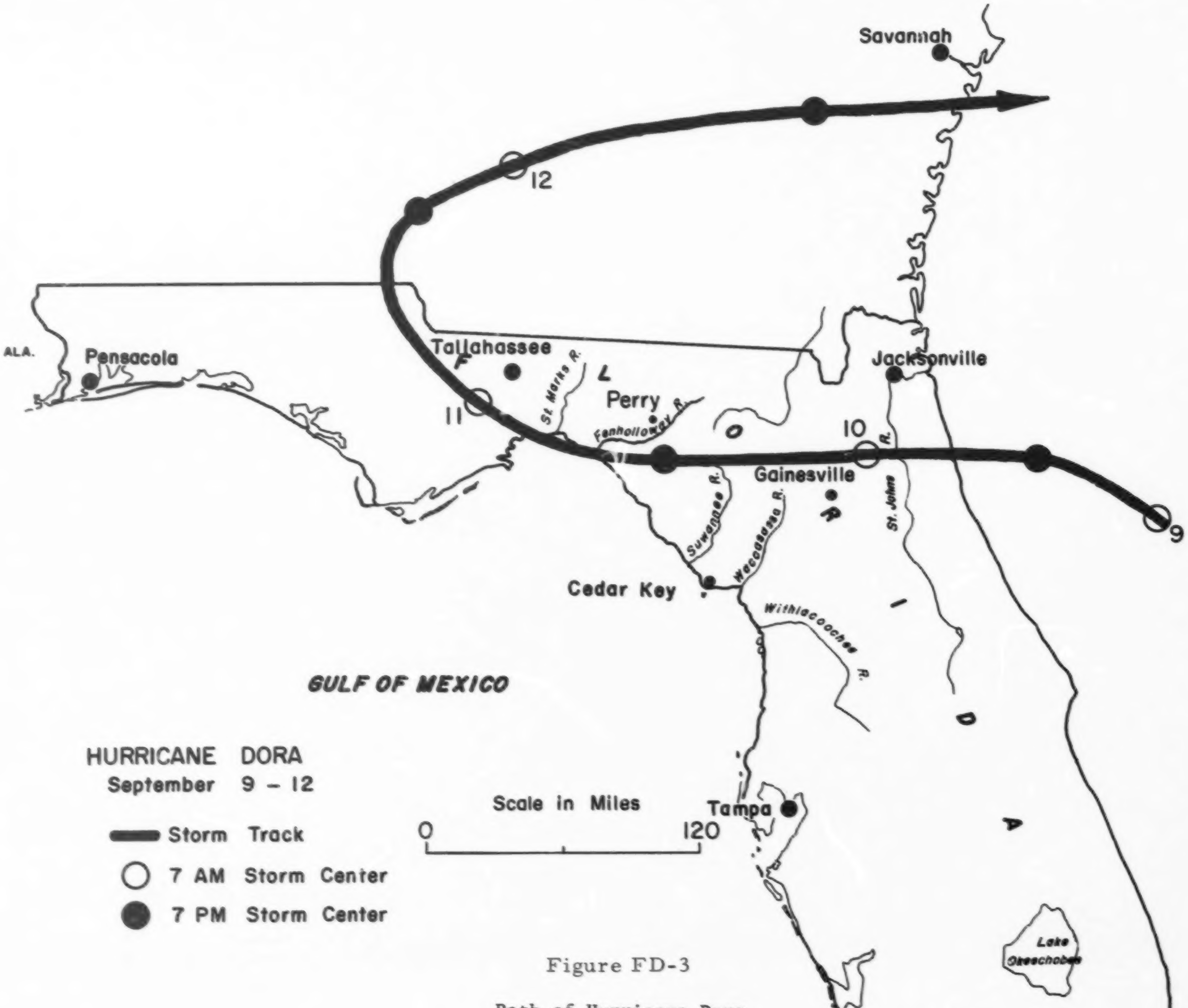

Savannah
12
ALA.
Pensacola
Tallahassee
F
L
St Marks R.
Perry
Fenholloway R.
O
11
10
R.
Jacksonville
Gainesville
R
Suwannee R.
Waccasassa R.
St. Johns
Cedar Key
Withlacoochee R.
I
D
A
9
GULF OF MEXICO
HURRICANE DORA
September 9 - 12
Storm Track
7 AM Storm Center
7 PM Storm Center
Scale in Miles
0
120
Tampa
Lake Okeechobee

Figure FD-3

Path of Hurricane Dora
September 9-12, 1964

Geological Survey installation at Station F-101. This station is equipped with a water stage recorder; the flow is unregulated, and the daily discharge is published. No other daily discharge records exist, other than at Station F-1011. Station F-101 is located on the headwaters of the river some 24 miles above tidal influence. To estimate the fresh water contribution to the estuary, measurements of flow nearer the estuary must be made. The principal tributary below Station F-101 is Spring Creek, which enters the river immediately below Station F-104. Hence a series of streamflow measurements were made at different stages of flow at Stations F-103 (Spring Creek near its mouth) and F-104 (the Fenholloway immediately above the mouth of Spring Creek). The sum of these observations represents fairly closely the total fresh water discharge of the river. Locations of all stations are shown on Figure A-5.

It was found that a quite good correlation exists between the discharge at Station F-101 and the sum of the discharges at Stations F-103 + F-104 on the same day. The regression lines are plotted on Figure FD-4. It will be noted that the slope of the regression line changes at about 100 cfs at Station F-101. One may enter Figure FD-4 with the daily discharge recorded at Station F-101 and obtain the discharge at Stations F-103 + F-104. To this value should be added about 10 per cent for the ordinary minor amount of fresh water contribution below these stations. Table FD-2 has been derived from Figure FD-4 to indicate the discharge at Stations F-103 + F-104 on the days when samples for analysis were collected. The amount to be added for inflow below Stations F-103 + F-104 has not been indicated, since while 10 per cent is regarded as a good average figure, it will be somewhat smaller during periods of drought and considerably higher during floods. Recourse to daily rainfall data will assist in making adjustments if desired. However, the additional inflow during droughts is so small as to be inconsequential, and such inflow during severe floods can be estimated by applying a reasonable factor. During floods the entire estuary is virtually a fresh water stream, a situation which frequently persists for some distance into the Gulf.

It should be emphasized that the relations shown on Figure FD-4 between discharge at Station F-101 and Stations F-103 + F-104 are *applicable only to the period of the present study,* roughly January, 1964, to July, 1965. The ratio of flow at F-104 to that at F-103 varies substantially due to mill operations and regulation of the flow from the drainage canals. For future studies, it would be highly desirable to have the U. S. Geological Survey install a recording gage at Stations F-104 and F-103 or at other suitable locations to measure more accurately the fresh water contribution to the estuary.

One of the chief purposes of estimating streamflow is to gain some idea of the dilution afforded the wastes discharged to the river and the estuary. For this purpose, recourse was had to the streamflow recorded at the USGS gaging station at Sampling Station F-1011, immediately below the point of discharge of the wastes from the mill. While, as indicated previously, the records at Station F-1011 are not regarded as good, nonetheless average values of flow at Station F-1011 can be compared with average flows at other stations to get a reasonable idea of dilution.

For the 19 months of the study (January, 1964-July, 1965) the ratio of fresh water flow delivered to the estuary to that at Station F-1011 was about 2.5. Actually this ratio varies from about 2 for fresh water flows above 400 cfs to the estuary to about 3 for flows below this amount. The higher ratio at lower flows may indicate the effect of the 78 cfs ground water contribution from the mill effluent. It is interesting to note that the median ratio of fresh water contribution to the estuary to the flow of Station F-1011 for the 48 sampling dates (Table FD-2) is 2.3; also that the median flow to the estuary for the 19 months of the study is 420 cfs, while that for the 48 sampling dates is 450 cfs. It appears that the flow conditions on sampling dates taken as a whole represented fairly well the general regimen of flow.

Using the flow at Station F-101 as the best indication of variations in runoff conditions during the period of the study, it will be noted from Table FD-3 that such variations range from 2.7 cfs to 2710 cfs, with a mean of 130 cfs and median of 87.6 cfs for average daily flows. The peak flow from Hurricane Dora was 3210 cfs. The rather flashy nature of flood flows makes the median values more representative of the normal than the mean for a short period such as the 19 months of the study. The ten-year mean was 73.1 cfs. The flow on the 48 sampling dates (Table FD-2) ranged from 5 cfs to 1130 cfs with a mean of 122 cfs and a median of 89 cfs, confirming the impression made above that the conditions of flow on sampling dates represented fairly adequately the general regimen. The data given above for Station F-101 can be applied to flow to the estuary by means of Figure FD-4 and the procedures mentioned previously. The average time of lfow from Station F-101 to Stations F-103 + F-104 is about one day under average conditions, but error due to this factor in using flow at Station F-101 to estimate flows at Stations F-103 + F-104 is eliminated to a considerable degree by the fact that streamflow measurements at these stations used to plot Figure FD-4 were made on the same day and on dates when flows were not changing.

Reference has been made in the discussion of rainfall to the extraordinary wetness of 1964. Some idea of the relation of this year to others during the progress of the present study can be obtained from Table FD-4. The "water year" extends from October of one year through September of the next year.

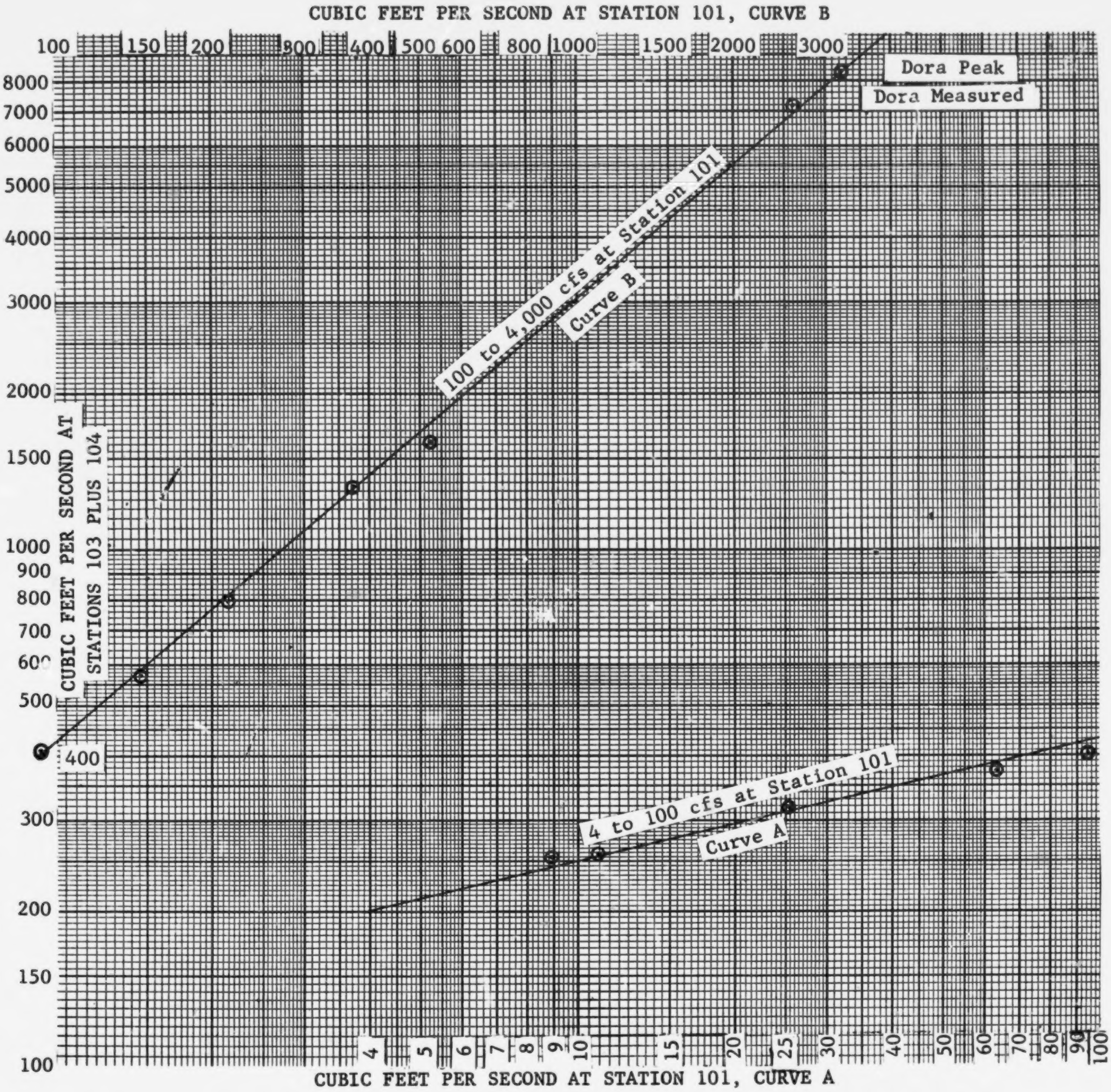


Figure FD-4

Relation of Streamflow at Station F-101
to that at Station F-103 plus F-104

Table FD-2

FENHOLLOWAY RIVER STREAMFLOW ON SAMPLING DATES

Cubic Feet per Second

Date	Station			
1964	F-101	F-1011	F-103 + F-104	Estuary
1/8	53	81	370	410
1/21	232	370	880	1000
2/10	154	267	610	680
3/23	180	322	700	775
3/31	83	198	410	450
4/7	33	124	330	360
4/13	21	97	295	325
4/20	11	72	255	280
4/27	9	64	240	265
5/4	379	650	1350	1500
5/6	316	488	1150	1300
6/1	9	76	240	265
6/15	11	78	255	280
6/22	5	62	210	230
6/29	14	90	270	300
8/6	288	595	1050	1175
8/10	331	575	1175	1350
8/13	526	1130	1750	2000
8/17	275	550	1000	1125
8/20	203	488	770	850
8/24	317	764	1150	1300
8/31	162	430	640	710
9/1	142	402	570	630
9/22	453	916	1550	1750
10/20	85	250	415	460
11/3	16	118	275	300
11/12	9	84	240	265
11/17	8	92	235	260
11/30	44	167	350	390
12/16	137	307	550	610
1965				
1/4	33	136	330	360
1/7	26	87	310	345
1/13	16	89	275	305
1/22	11	86	255	280
1/26	24	118	305	335
2/2	44	140	350	390
2/4	36	126	340	375
2/8	46	153	360	395
2/16	96	229	425	470
3/1	51	162	365	400
3/5	215	423	800	885
3/10	117	255	485	535
3/15	84	184	410	450
3/22	209	404	790	875
3/24	164	328	650	720
3/31	93	202	420	465
6/23	27	124	315	350
7/12	71	189	395	440
Average	122	277	560	625
Median	89	194	410	450

Drainage Areas in Square Miles		
Station	F-101	90
	F-1011	145
	F-103	92
	F-104	188
	F-103 + F-104	280
	F-1 (mouth of estuary)	333

NOTE: The drainage areas tabulated for Stations F-101 and F-1011 were carefully determined from maps, actual surveys, and field inspection. They differ from those used by the Geological Survey which are respectively 60 and 110 square miles.

Table FD-3

STREAMFLOW (CU. FT. PER SEC.) AT STATION F-101
MONTHLY AVERAGES AND EXTREMES
JANUARY 1964-JULY 1965 INCLUSIVE

Data from U. S. Geological Survey

Month	1964 Mean	1964 Maximum	1964 Minimum	1965 Mean	1965 Maximum	1965 Minimum
January	152	316	5.3	22.9	51	11
February	175	616	98	58.6	96	32
March	216	444	83	135	226	51
April	57.4	442	6.7	40.9	165	5.8
May	147	437	10	24.1	113	2.9
June	14.2	48	4.4	37.2	177	2.7
July	194	609	23	80.3	215	26
August	327	606	162			
September	560	2710	37			
October	87.6	184	21			
November	13.8	50	6.8			
December	116	260	32			
Year	172	2710	4.4			

Table FD-4

AVERAGE ANNUAL FENHOLLOWAY STREAMFLOW AT STATION F-101

Water Year	Streamflow	Calendar Year	Streamflow
1960-61	40.1 cfs	1960	104 cfs
1961-62	12.1 cfs	1961	18.4 cfs
1962-63	38.7 cfs	1962	16.8 cfs
1963-64	154.2 cfs	1963	34.4 cfs
1964-65	59.4 cfs	1964	172 cfs

NOTE: The ten-year average streamflow (1955-65) was 73.1 cfs.

The calendar year 1964 witnessed the highest annual streamflow of record on the Fenholloway and other streams in Northeast Florida. Streamflow at Station F-101 was of flood proportions (above 300 cfs) for most of the time from the middle of July to the end of September, as indicated on Figure FD-5. Extensive flooding of lands adjacent to the river occurs at flows exceeding 400 cfs. The effect of Hurricane Dora is indicated. The peak flow of 3210 cfs is estimated to have a recurrence interval of more than 50 years (2). The peak flow at Station F-1011 was measured at 4810 cfs. The peak discharge at Station F-103 + F-104 is estimated at about 9000 cfs, and at least 10,000 cfs in the estuary. Large areas of land adjacent to the river were under water for over two weeks. Serious public health hazards would result from floods of even less magnitude if substantial areas adjacent to the river and estuary were extensively developed without flood control works. These would have to involve extensive diking since flood control dams are not economically feasible in the flat topography.

FE. TIDAL PHENOMENA

The tidal patterns of the Fenholloway Estuary are quite similar to those described for the Waccasassa. The Fenholloway Estuary mouth is only about 25 miles from the primary tide station of the U. S. Coast and Geodetic Survey at St. Marks River Entrance. Two tide gages were installed in connection with the estuary study. One was located in the Gulf at a large bird rack about two miles west of the estuary mouth. High and low water data at this location are the same as at St. Marks, as is the range of tide. Mean range is 2.4 feet and diurnal range is 3.3 feet. This gage was blown over by Hurricane Dora on September 11, 1964, but it was shortly re-established at another bird rack in the vicinity.

The other tide gage was installed at the estuary at Hicks Camp (Station F-106) and MSL datum was established by survey from a U. S. Geological Survey bench mark. The location of these two recording tide gages is shown on Figure A-5. In addition, two staff gages were installed, one at the mouth of the estuary (Station F-1) and one at the junction of Slough Creek and the estuary (Station F-111) just south of Bird Island. Data were determined from surveys from the Hicks Camp gage. The locations of the three gages in the estuary are shown on Figure FC-1.

During the period of study of the Fenholloway, the mean ranges at several points in the estuary were found to be as follows:

Station F-1, Estuary mouth	2.54 feet
Station F-1061, Bird Island	2.35 feet
Station F-106, Hicks Camp	1:87 feet

The time of travel of the tidal wave along the river is longer than the theoretical time, which is obtained from $v = \sqrt{gd}$. The very rough bottom of fractured hard limestone, with many boulders and ledges, and the heavy growth of reeds and other vegetation at the edge of the river provide sufficient roughness to reduce the velocity of the wave to about 50 per cent of the theoretical velocity.

The tidal wave in the Fenholloway is a progressive wave, as is that in the Waccasassa Estuary. The times of occurrence of the mean tidal stages at Station F-106 (Hicks Camp) were found to be:

Mean High Water

St. Marks Entrance plus 32 minutes
Bird Rack Gage plus 40 minutes

Mean Low Water

St. Marks Entrance plus 53 minutes
Bird Rack Gage plus 52 minutes

Hicks Camp is essentially the head of the estuary, although tidal effects extend about two miles farther upstream, as shown on Figure A-5. Normal chlorides at Hicks Camp and for some distance below are little affected by sea water, and strictly speaking, actual estuarine conditions begin about at Bird Island. Above this point, tidal river conditions exist. The true estuary is thus quite short and varies in length with the amount of fresh water discharge. For the purposes of this study, the estuary and tidal river are not differentiated, and the estuary is considered to extend to Hicks Camp. The tidal prism is about 15×10^6 cubic feet, which is much smaller than the Waccasassa Estuary, and hence the flushing time is shorter, as discussed under FK. DIFFUSION AND POLLUTION ASSIMILATION.

The mean slope of the Fenholloway is considerably steeper than that of the Waccasassa, particularly that reach of the river above Bird Island. On Figure FE-1 are shown the comparative slopes found on the two rivers at mean tide level and normal fresh water flows. The greater slope of the Fenholloway causes distinctly higher downstream velocities than in the Waccasassa. As one result, the salinity intrusion is considerably shorter in the Fenholloway. It was noted that a bottom salinity intrusion rarely showed up above Bird Island (about 8300 feet from the mouth) except during spring high tides or when there was a strong and sustained southerly wind.

The Fenholloway Estuary is stratified to a greater extent than is the Waccasassa. However, it does not fit into the classification of highly stratified estuaries at normal flows. At a fresh water discharge of 300 cfs, the ratio of fresh water discharge during a half tidal cycle to the mean tidal prism is about 0.75. This would indicate a degree of mixing characteristic of a partially-mixed

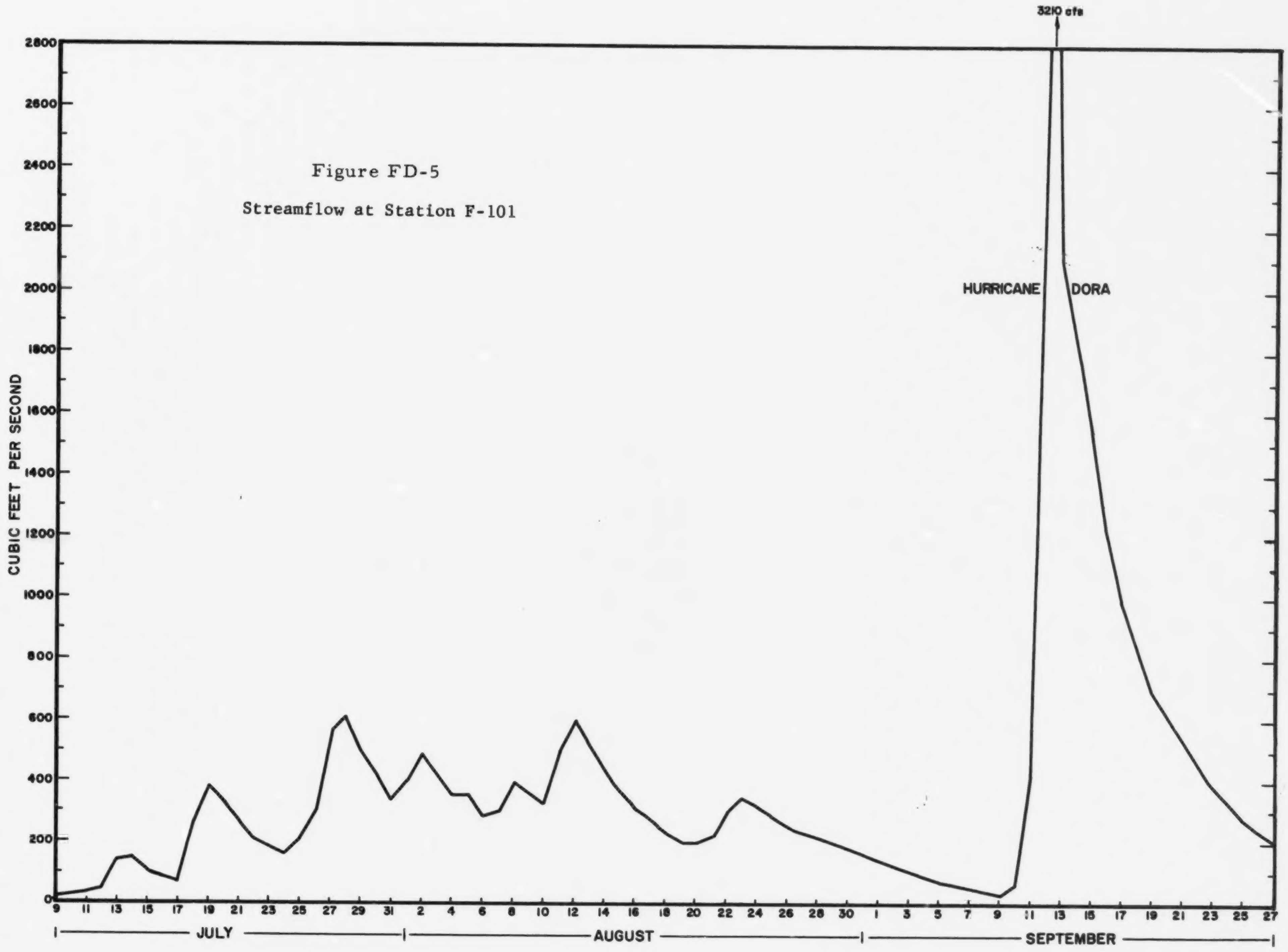


Figure FD-5

Streamflow at Station F-101

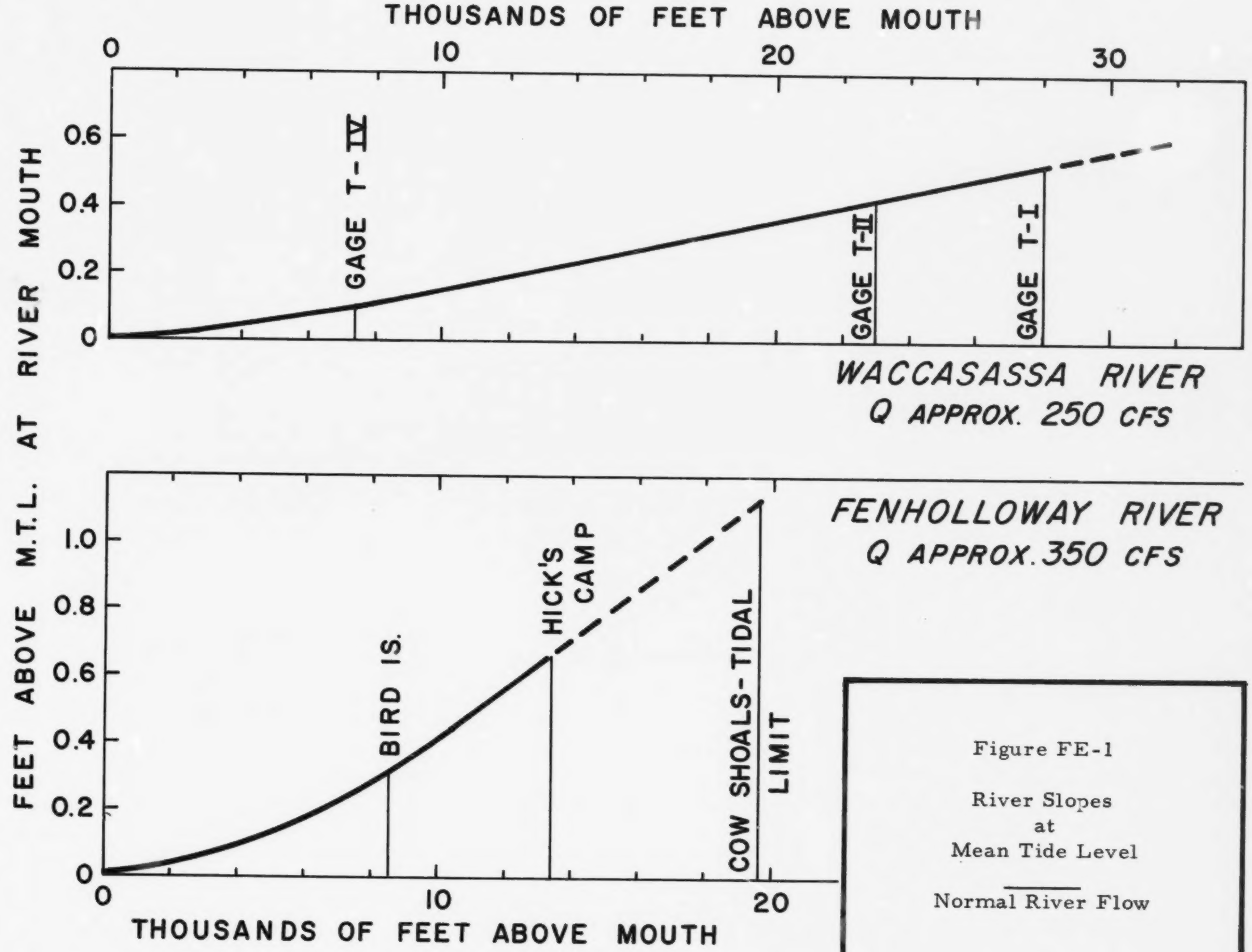
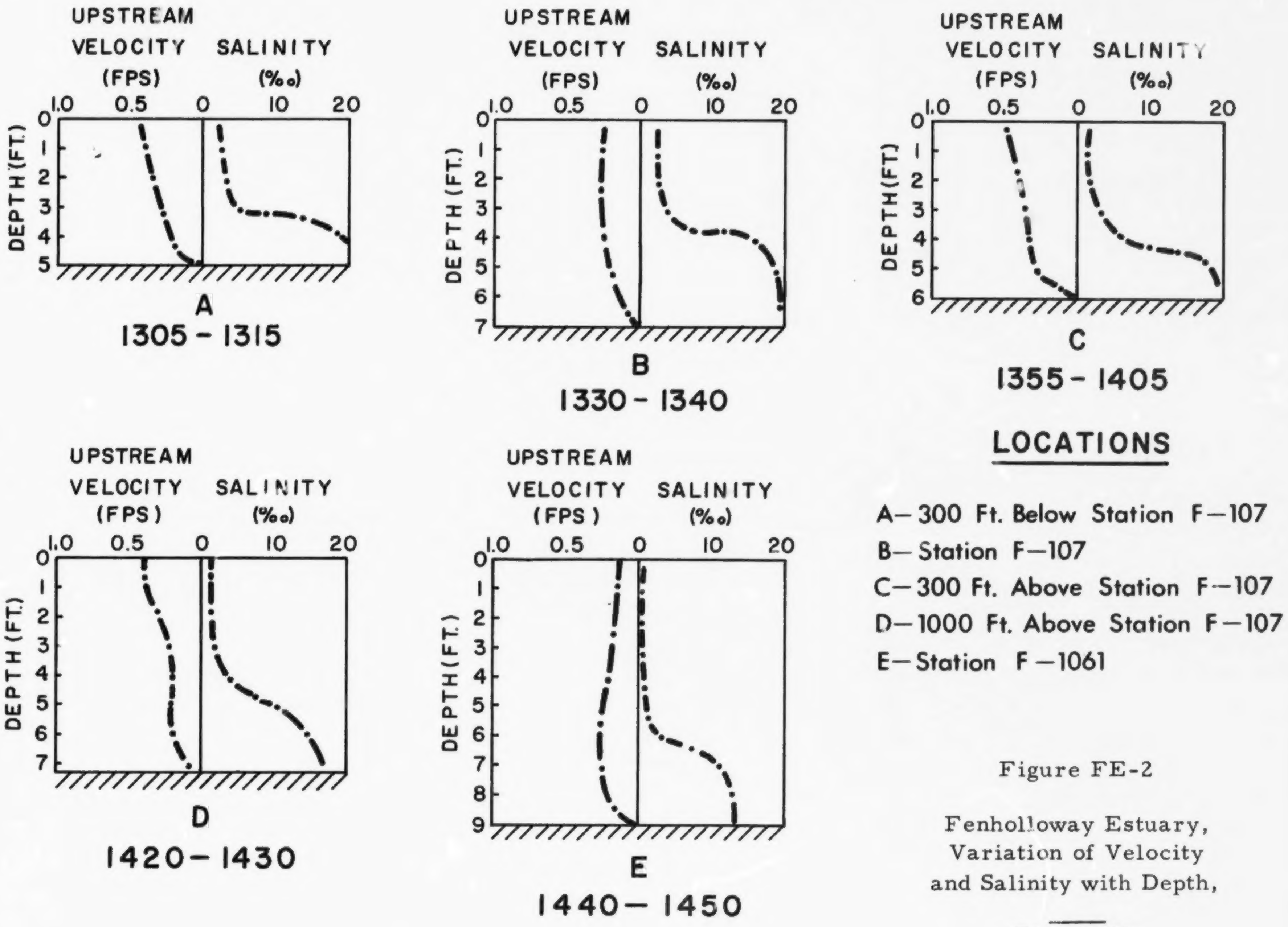


Figure FE-1

River Slopes
at
Mean Tide Level

——— Normal River Flow



A
1305 - 1315

B
1330 - 1340

C
1355 - 1405

D
1420 - 1430

E
1440 - 1450

LOCATIONS

A — 300 Ft. Below Station F—107
B — Station F—107
C — 300 Ft. Above Station F—107
D — 1000 Ft. Above Station F—107
E — Station F—1061

Figure FE-2

Fenholloway Estuary,
Variation of Velocity
and Salinity with Depth,

Flood Tide
January 22, 1965

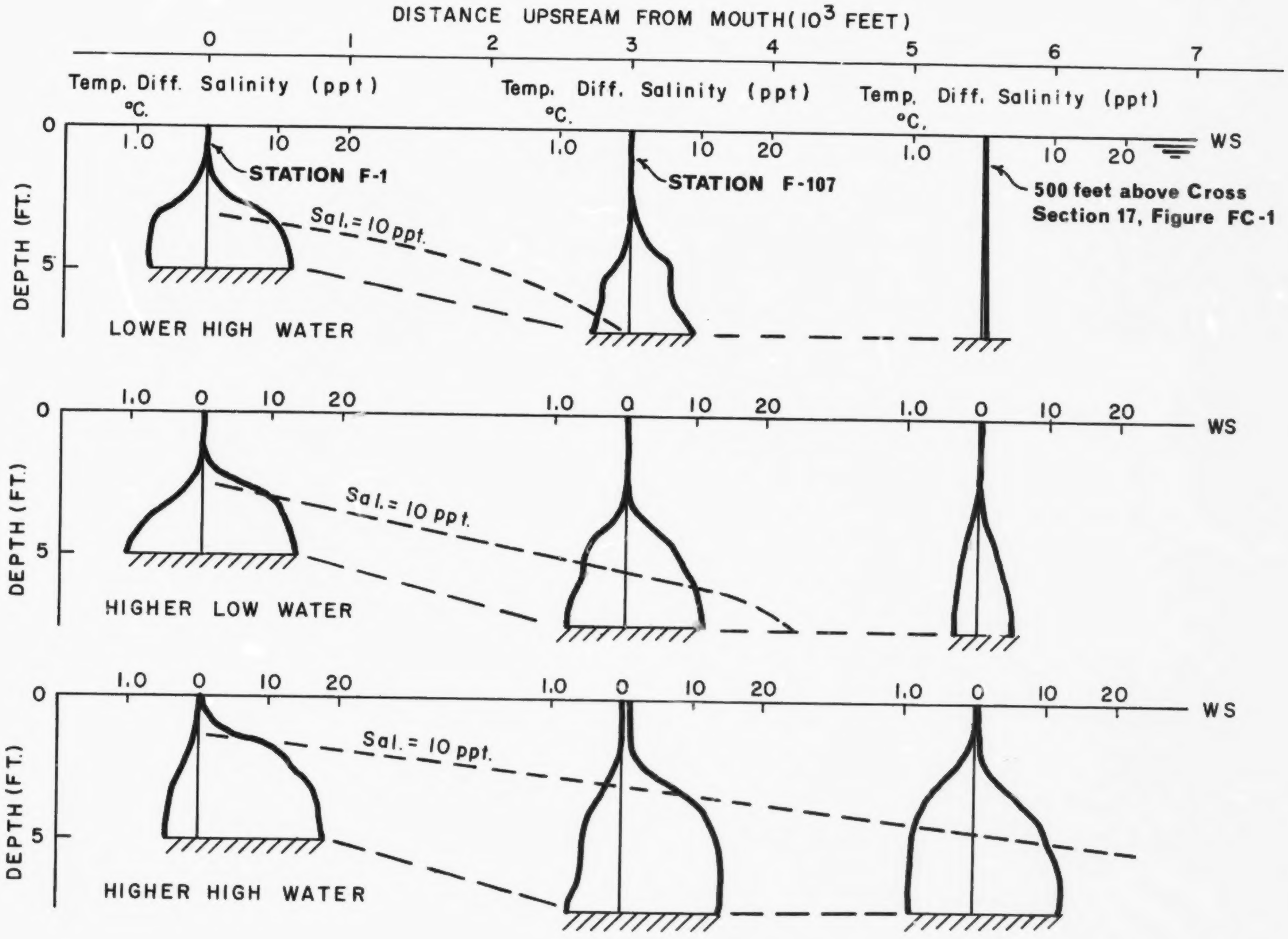


Figure FE-3

Vertical Temperature and Salinity Gradients,
Fenholloway Estuary, March 24, 1965

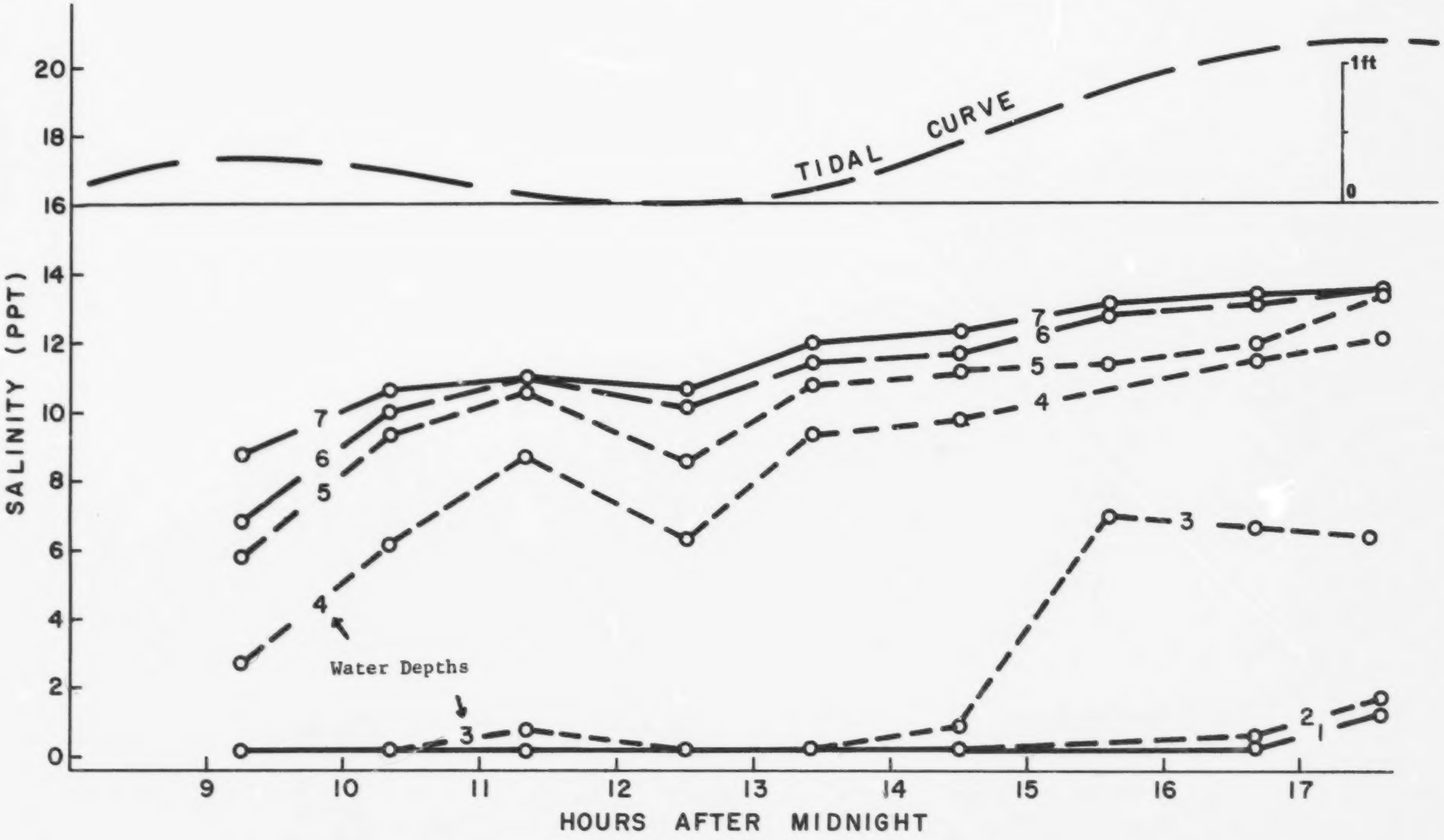


Figure FE-4

Fenholloway Estuary,
Extended Study of Salinity
Station: F-107
March 24, 1965

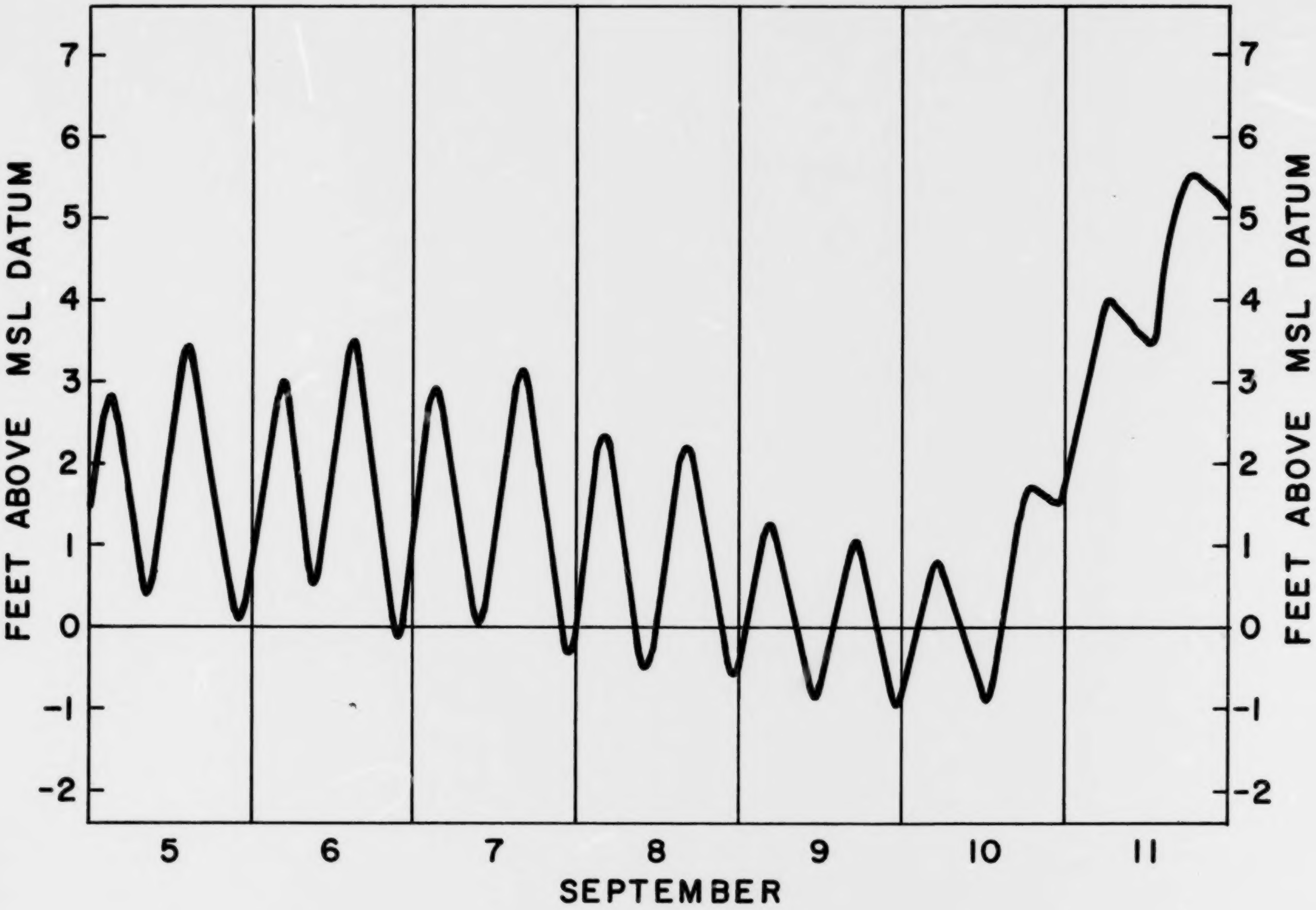


Figure FE-5

Fenholloway Estuary,
Hicks Camp Gage (Station F-106) Record
Sept. 5-11, 1964

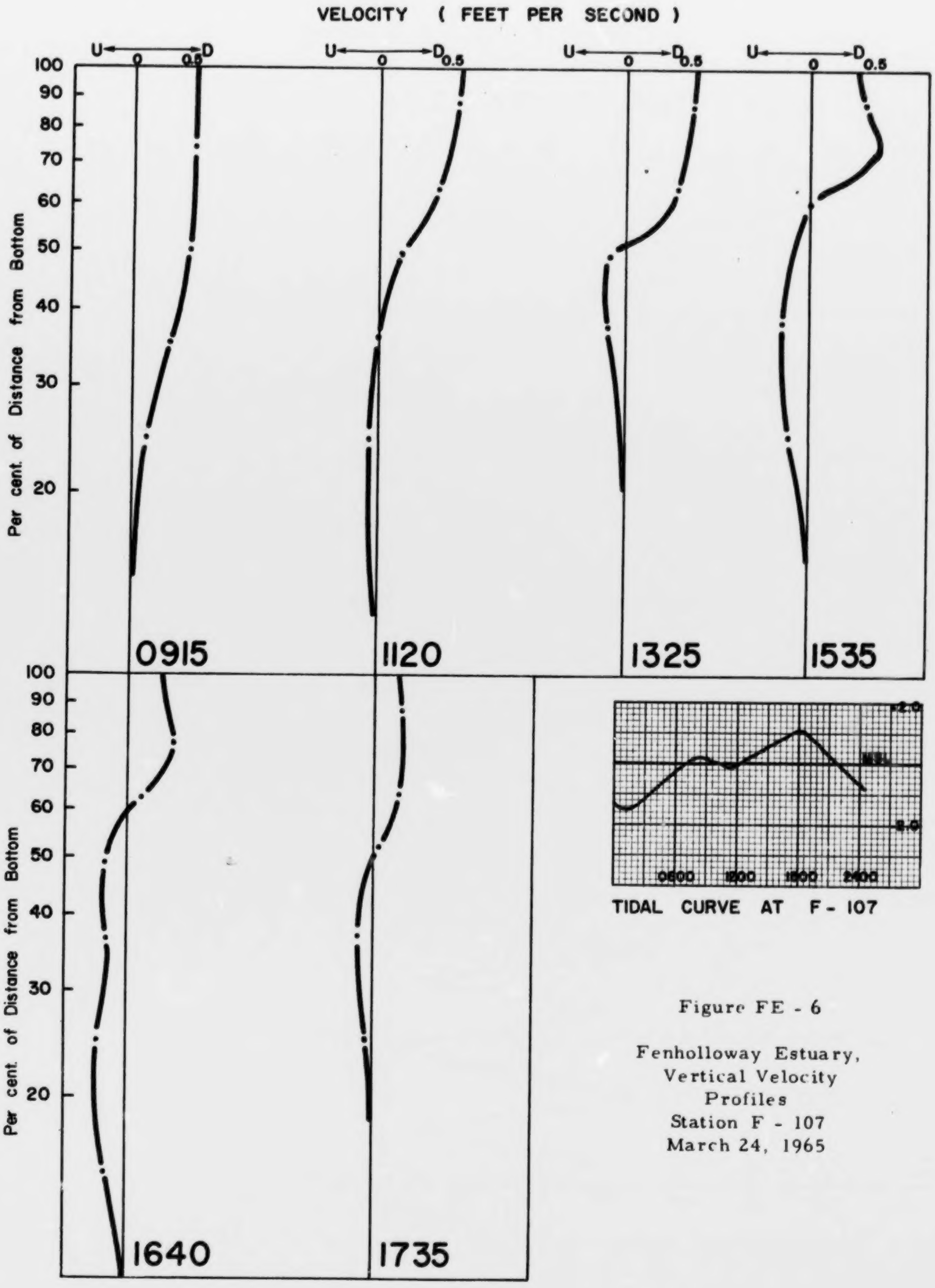


Figure FE - 6

Fenholloway Estuary,
Vertical Velocity
Profiles
Station F - 107
March 24, 1965

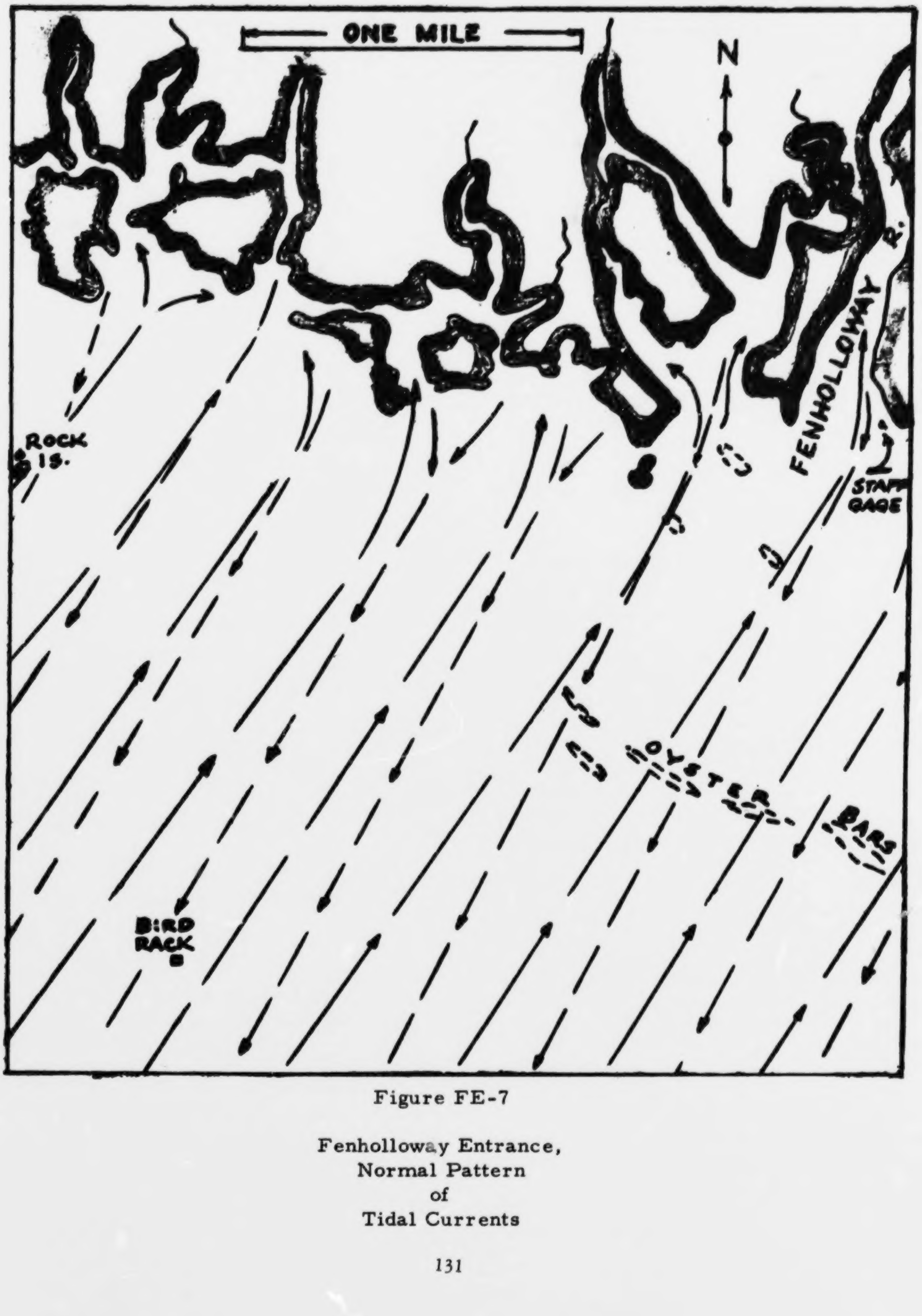

ONE MILE
N
FENHOLLOWAY R.
ROCK IS.
STAFF GAGE
OYSTER BARS
BIRD RACK

Figure FE-7

Fenholloway Entrance,
Normal Pattern
of
Tidal Currents

estuary, but on the high end of the classification. Of course as the fresh water flow increases, the degree of stratification increases. At 400-600 cfs, the lower portion of the estuary becomes highly stratified, while the upper portion of the estuary (above Bird Island) becomes essentially a fresh water stream. When the flows exceed 1000 cfs, salinity intrusion becomes slight and is confined to a reach of a few thousand feet near the mouth of the river.

The type of salinity intrusion found under normal flow conditions is shown in Figure FE-2. On January 22, 1965, salinity and velocity observations were taken in the lower portion of the estuary (between Bird Island and the mouth). The flow was approximately 280 cfs, and the existence of a fairly distinct halicline is shown by the nearly horizontal portions of the salinity gradients, particularly at those locations near the mouth.

In Figure FE-3 the salinity gradients for the lower 1.4 miles of the estuary are shown at three tidal stages. In this case, the fresh water discharge was approximately 600 cfs. The tidal pattern was such that there was very little difference (about 0.3 foot) between lower high water and higher low water. There was also a sustained wind from the south of 15-20 mph, which began to blow shortly after lower high water and continued throughout the period of observations. The presence of a saline wedge is clearly shown by the plotted salinity gradients at the three stations and the position of the 10°/oo salinity contour below the water surface.

Figure FE-4 shows the time variation of the salinity at various depths at Station F-107. The tidal curve is shown above the plot salinity. The effect of the southerly wind on the increase in salinity intrusion is shown by the fact that the salinity was somewhat higher at low water than it had been on the preceding lower high water, at which time there was little or no wind. Of course the salinity increased rapidly to the next succeeding high, under the influence of the higher tide and the continuing wind.

Wind effects on the tides in the vicinity of the Fenholloway entrance are comparable with those in Waccasassa Bay, with the exception that there is no embayment at the Fenholloway to cause concentration. Winds from the northerly quadrant depress the water level and delay the occurrence of high or low stage; winds from the southerly quadrant raise the water level and cause the time of high or low stage to be advanced. Winds from the other quadrants have little effect except on the direction of the tidal currents.

Figure FE-5 shows the effects of the high velocity winds at the head of the estuary during the passage of Hurricane Dora in September, 1964. It is apparent that high water occurred at about 1530 hours and reached an elevation of about 5.5 feet above MSL datum. The regular pattern of the tidal highs and lows is superimposed on the water level set-up caused by the hurricane winds.

On Figure FE-6 are plotted vertical velocity profiles measured at the centerline of the estuary at Sampling Station F-107, about 3500 feet from the mouth. It will be noted that the surface flow is downstream at all times during this cycle, due to the fresh water flow of approximately 600 cfs, which is several times the normal dry weather flows. At lower flows there is a reversal of current on the surface at this station. The upstream flow of saline water near the bottom is seen to begin about 1120 hours (before low water) and to continue until higher high water. The vertical velocity profiles shown here for the Fenholloway are in general quite similar to those found in the Waccasassa.

Tidal currents in the shallow offshore areas outside the Fenholloway entrance show a pattern similar to that of the currents in Waccasassa Bay, in that the approach of the tidal flood is from the southwest and the ebbing tidal currents tend to take a more southerly course in the absence of local winds as shown in Figure FE-7. The net effect of the more southerly trend of the ebb currents is to cause a slow southeasterly displacement of the fresh water flow from the streams in this area, including pollution where present.

FF. MICROBIOLOGY

Introduction

Biological work during 1964-65 consisted of two lines of investigation in the Fenholloway region. These were: (a) qualitative and quantitative enumeration of the suspended microbiota, with the significance of their presence; and (b) analysis of the sediment-water interface communities. The location of Fenholloway sampling stations is indicated on Figure A-5. In addition, a comparison was made of the current Fenholloway data with some obtained there and in the Steinhatchie, Econfina, and Aucilla Rivers in 1953 and 1954, before the Buckeye Cellulose mill was built.

Sampling

The total number of samples was small due to the vagaries of rainfall, floods, and winds. The plankton samples were taken at the surface, chilled for transit, and analyzed as described under F. MICROBIOLOGY for the Waccasassa. A few were preserved with formalin (3 per cent) when it was necessary to keep them several weeks.

The Estuary and Nearshore Gulf Stations

Inasmuch as the estuary below Station F-106 and nearly to the mouth at Station F-1 is virtually barren of suspended microbiota other than bacteria [illegible] good deal of attention was paid to sediment-water interface conditions where most of the biological activity in the estuary takes place. Core samples for a study of these conditions were taken from the estuary and from nearshore Gulf stations. Other than bacteria, suspended microbiota do not become of significance until the mouth of the estuary is reached and then in the waters of the Gulf. Because substantial recovery from pollution in the estuary takes place in the nearshore waters of the Gulf, a number of sampling stations (Stations F-2 to F-11) were located in these waters.

Bottom Studies. Table FF-1 shows the composition of the interface microbiota at Stations F-1, F-2, F-3, and F-4, June 1, 1964. Station F-1 is at the mouth of the estuary, while Stations F-2, F-3, and F-4 are nearshore Gulf stations. The estuary was core sampled the same day, and Stations F-106 and F-107 showed a black mud as interface material. This was anaerobic and contained vast numbers of free living bacteria. Station F-106 (near the head of the estuary) had a few *Trepomonas rotans,* a zooflagellate characteristic of anaerobic organic substrates, and it also had small numbers of *Oscillatoria sp., Beggiatoa leptomitiformis, Chromatium okeni,* and *Vitreoscilla.* Station F-107 (at the confluence with the Henderson River) contained a few *Chromatium* and *Sarcina.* It is inferred that this last species is responsible for methane formation in the sludge banks. These deposits change location in the estuary but are fairly permanent gulfward of Station F-1, as shown on Plate III. These observations seemed to call for a more detailed study of core samples from Stations F-106 and F-107.

The shallow areas of the lower estuary and the nearshore Gulf waters permitted obtaining cores by hand. These samples showed a dominance of photosynthetic diatoms and also a large biomass of colorless saprophytic euglenids and bacteria-consuming colorless ciliate protozoa. Numbers decreased according to the amount of sand in the interface and increased sharply as the amount of silt and/or organic matter increased. Since the interface is always underlaid, although at varying depths, by a black anaerobic base, it was thought that the more nearly this approached or constituted the interface, the greater would be the population decrease (of algae and protozoa) in the interface. This assumption was based on failure in many cases to find protozoa and, of course, algae in the black underlayer except in very isolated instances, and also upon the known toxicity of H_2S, which is generally abundant in the black area. However, this blackness may also be due to other sulfur compounds.

Cores taken in the estuary and nearby Gulf were generally extremely black with no brown interface, or at best a very thin one. They were examined for living organisms as soon as practicable after reaching the laboratory, and the nature of the interface was noted; i.e., color, composition, microbiota. The occurrence of living microorganisms in numbers per ml was ascertained, and those recently dead were listed. Interface material was then seeded into whole wheat culture media in fingerbowls to see what would eventually develop, and the core was allowed to stand at ambient temperatures for as long as twenty days. This also indicated what developed with no new river water being added (no additional pollutant being put in) as bacterial action degraded the organic matter present at the time the core was taken.

The results were interesting and unexpected. It should be remembered that water samples (plankton) from this area rarely showed more than an occasional saprophytic flagellate such as *Trepomonas rotans* or a ciliate such as *Lembus fusiformis* except when high water diluted the estuary, and then only a very few organisms. Cores were taken at various locations from Station F-106 downstream. This was to cover a variety of habitats, if such existed, in the area. On December 29, 1965, a fresh core taken near the right bank between Stations F-107 and F-1 showed a gelatinous interface, brown to green in color, and with no sand. It was about two to four millimeters in thickness, shading into a deep black mud. The dominant organisms were *Oscillatoria spp.* and *Beggiatoa alba,* which formed an interlaced moving (both are motile) network. In this, besides other bacteria, were the following species:

Sulfur bacteria	8
Blue-green algae	3
Diatoms	4
Amoebeae	2
Zooflagellates	4
Ciliates	3
TOTAL	24

These numbered in excess of 660/ml. The two dominants were not counted. The numbers of sulfur bacteria are considered strikingly significant. These occur in huge quantities in the runs from sulfur springs *if there is a small amount of dissolved oxygen present,* but occurrence elsewhere has been sparse both as to numbers of filaments and biomass. *B. gigantea* and *B. mirabilis* have not been found heretofore except in salt or brackish (ca. 15,000 mg/l) water, but in this instance it appears that at times this area is fresh water, at least for a few hours on a very low tide. Their abundance here indicates also sulfur compounds which are found in the mill wastes and from Hampton Spring as mentioned under FJ. CHEMICAL CHARACTERISTICS.

It is evident that a considerable potential for the degradation of organic matter exists in the interface even when there is no suspended biota other than bacteria. On December 28, 1965, Station F-107 had 23 species totaling more than 401 individuals per ml, and with about

Table FF-1

NUMBERS OF MICROORGANISMS PER ML IN INTERFACE MATERIAL AT NEARSHORE GULF STATIONS F-1 TO F-4, JUNE 1, 1964

	Stations			
F-1	F-1	F-2	F-3	F-4
Bacteria				
Achromatium oxaliferum	1			
Beggiatoa alba	4			
Beggiatoa leptomitiformis	12			
Sphaerotilus natans, strands	4	4		
Blue-green algae				
Merismopedia glauca		80	4	24
Chlorophyceae				
Dunaliella salina	4		4	12
Nannochloris atomus ?		2400	4800	600
Pyramidomonas grossi		24	16	12
Pyramidomonas sp.		4	4	40
Thoracomonas sp.			32	64
Euglenophyceae				
Euglena gracilis	1			
Euglena viridis	3	1		
Eutreptia viridis		4	3	1
Notosolemus apocamptus		2		
Protaspis glans		4	4	1
Cryptophyceae				
Chilomonas marina		24		
Chroomonas sp.		8	24	24
Cryptomonas erosa				1
Rhodomonas lacustris		56	16	8
Chrysophyceae				
Calycomonas sp.		160	4	16
Incertae sedis		2400	480	240
Dinoflagellata				
Ceratium furca			1	
Diplopsalopsis rotundata	2	3	1	
Glenodinium foliaceum	3	6	4	
Gymnodinium alba		8		
Gymnodinium sp.				.5
Gyrodinium pingue		1		
Massartia rotundata				12
Prorocentrum micans	4	8	6	8
Prorocentrum triangulatum	1	2		
Protodinium sp.		8		
Unid. Dinoflagellata				.5
Bacillarieae (Diatoms)				
Actinoptychus undulatus		2	2	2
Amphora ovalis	1			
Amphiprora pulchellum		1		
Campylosira sp.		3	3	
Chaetoceras spp.		1600	800	160
Coscinodiscus spp.	2	8	2	1

Bacillarieae (Diatoms) Continued)

	Stations			
	F-1	F-2	F-3	F-4
Cyclotella spp.	32	64	80	284
Melosira monilata		2	1	
Navicula spp.	8	64	16	4
Skeletonema costatum	8	48		4
Synedra ulna	4			
Thalassiosira rotula		4	12	48
Unid. diatoms	8			
Rhizopoda				
Camptonema nutans	168	8		
Zooflagellata				
Bodo globosus		4		
Bodo sp.	4			
Diphanoceca grandis			1	
Monas sp.	180	60		
Monosiga ovata		4		4
Oicomonas termo	1280	80		
Paraphysomonas vestita	24			
Rynchobodo nasuta	40			
Unid. Zooflagellata	160	160	64	32
Ciliata				
Aspidisca sp.			1	
Euplotes sp.	1			
Lembus pusillus	164	8	1	
Mesodinium pusillus	1	1		
Strobilidium sp.			1	
Strombidium sp.		1		
Tintinnopsis minuta		8	1	
TOTALS	2124	7337	6388	1603

the same groups. At the same time, Station F-1 had 40 species and 205 organisms per ml:

Sulfur bacteria	4
Blue-green algae	4
Diatoms	7
Amoebeae	2
Zooflagellates	5
Ciliates	15
Colorless euglenids	2
Cryptomonads	1
TOTAL	40

Collectively this group is better able to carry out purification (picking up where the bacteria leave off) than those at Station F-106 or at Bird Island, where only bacteria were found alive. Station F-107 had a balanced group. This station is about 3000 feet above the estuary mouth (Station F-1) and near the junction with Henderson River.

No detailed comparison of cores above Station F-106 was made. But in the tidal reaches it is quite apparent that as soon as an appreciable influence of Gulf water is felt, the interface becomes an active zone. Furthermore, even though at times the organisms are not sufficiently abundant to reach a density of 1/ml, they are still present and if conditions become favorable, they become active.

If a core is allowed to stand for a few days to two weeks after the initial examination, dense growths may appear. It is possible to find 15 or 20 species in the original interface sample, then recover 30 to 40 additional species by the further use of the core.

In the series of cores from the general areas of Stations F-106 and F-107, a total of perhaps 60 different species has been enumerated and as many more by further use of the cores. This compares with five or six species recovered from the water samples. Obviously, current and a restrictive environment prevent plankton development during normal flow conditions. But given a little dilution and seeding from Gulf water, a certain number of microorganisms are able to survive in the interface and to be active or to become active under less restrictive conditions. The amount of work they do can only be inferred from present information, but both numbers and kind are significant – large numbers in the overall reduction of waste, and kinds in the reduction of specific wastes such as the use of sulfur compounds by the very large biomass of sulfur bacteria.

It is evident from the biotic examinations that decomposition of the cellulose mill waste in the estuary is almost wholly a bacterial function, and that algae and protozoa (plants and animals) are not involved in the estuary until there is a measure of dilution by Gulf water on moving seaward. But once the initial decomposition of the wood wastes is underway and with dissolved oxygen available, decomposition proceeds rapidly. This rapid decomposition is evidenced by the large numbers of microorganisms per ml in the interface material which use the decomposition products. These are sulfur bacteria, which can use H_2S or SO_4; green flagellates and blue-green algae, which can use PO_4 and NO_3; ciliates, zooflagellates, and rhizopods, which consume bacteria; and various others which can use soluble organic substances. These are all very abundant once the estuary mouth is passed, as shown in Table FF-1.

The core sample at Station F-4 was mostly sand, with little organic matter between the grains. This is a logical explanation for the paucity of interface organisms there.

The numbers in three of these cores were much higher per ml than in one ml of overlying water taken at about the same time. However, it is not to be interpreted that total decomposition is greater in the interface, even where the substrate is conducive to a high population as at Stations F-1, F-2, and F-3, than in the water column above the interface. Decomposition is greater only for the oxidizable matter settling into the interface. If we accept the interface depth as three millimeters, the number of organisms available for decomposition processes would be approximately 6000, 21000 and 18000/ml. If we accept 225/ml as the number of organisms in the overlying water, then a one millimeter column 2 meters in depth might contain 23^4, so that in settling, a bit of organic matter would be open to attack by a population more than ten times as great as in the interface. Nor does this number include bacteria, on which we have no good figures. It should be borne in mind, too, that the rate of settling in still water is governed by Stokes's Law, and in a current-swept area, the smaller particles may be totally and aerobically decomposed before reaching the bottom.

Stations F-1, F-2, F-3, and possibly F-4 and F-10 receive a heavy organic loading of cellulose mill waste. It is principally a high carbon waste with a sulfur content being reflected in the number of sulfur bacteria per ml. The number of visible bacteria is very high as the estuary enters the Gulf, and their presence is probably responsible for the large number of ciliates, 166 per ml, and zooflagellates, 1688 per ml, at Station F-1 at the mouth of the estuary. There is no satisfying explanation of why the numbers in Fenholloway interface material should not be greater (instead of lower) than in Waccasassa material.

Comparison of Interface and Plankton Populations. The numbers in interface samples are frequently much higher

Table FF-2

NUMBERS OF PLANKTON ALGAE AND PROTOZOA AT FENHOLLOWAY STATIONS F-1 AND F-2 ON CONSECUTIVE SAMPLING DATES

	Station F-1		Station F-2	
Date	No. Species	No. Individuals/ml	No. Species	No. Individuals/ml
1/11/64	14	2200	22	3373
4/14/64	15	117	17	122
4/17/64	7	7	22	354
5/6/64	20	30	26	3792
6/1/64	26	1954	43	7531
8/18/64	21	866	27	1557
8/24/64	34	3683	31	2521
10/26/64	7	2786	22	11202
10/28/64	8	12830	15	2908
11/17/64	33	3422	13	6455
2/7/65	5	5	13	851
4/1/65	16	942	16	1084

than those in comparable plankton samples. Interface counts are conservative becuase the sediment interferes with counting and with recognition. Often, too, their biomass tends to be large because of their ciliate and colorless euglenid populations. But the plankton numbers in the Fenholloway stations near the estuary mouth show considerable variation as shown in Table FF-2. The estuary water contains virtually no algae or protozoa except a few when the river is flooding; hence at high water periods the estuarine species are sharply reduced. However, despite the high carbonaceous nature of the river water, it is still rich with nutrients for bacteria and for some of the algae and protozoa, so there tends to be a constant arc of bacteria, algae, and protozoa around the estuary mouth, and its position is largely determined by the stage of tide and the river discharge. Stations F-1, F-2, and F-3 apparently are those most enriched by the estuary, receiving a substantial loading of organic waste.

The River Immediately Below Station F-1011

The large decrease in suspended solids, lignins, and other parameters below the point of discharge of the kraft mill waste effluent near Station F-1011 was somewhat superficially investigated as to the role of biological factors. Some interesting results developed.

The Fenholloway flows through a wide, marshy, swampy area beginning just below Station F-1011 and extending several miles down to the Perry-Foley airport. In this swampy area there is a heavy growth of shrubs and trees which are constantly contributing debris to the river and to the embayed areas. There are side drainages as well as Swain Spring which add dilution water. The gross effects of the debris-clogged and partially-stilled areas are to settle out much of the suspended matter, or to provide a lodgment for bacterial slimes onto which it can be adsorbed. Once adsorbed and held in place, the solids are subject to bacterial degradation for a much longer time than if they were hurried down in the swift river current. It should be remembered that bacterial digestion of wood pulp is a much longer process than for an organic substrate such as sewage solids.

This is far from the whole story. Bacterial digestion liberates much available food for higher organisms if they are present. Censuses of the organisms in the Fenholloway at Station F-1011 prior to the introduction of wastes at Station F-1011 revealed very few plankton organisms. But on January 21, 1966, the interface of a core sample there contained a good representative seeding. The side drainages in the swampy area added more and different organisms. Swain Spring added 52 species at one sampling alone, including a heavy concentration of sulfur bacteria.

Nevertheless, the shallow water areas were low in organisms other than bacteria. The ciliates and zooflagellates were strikingly reminiscent of those found in Imhoff tanks and indicated anaerobic conditions even in water a few inches deep. At Station F-106 there were 13 species or more than 1200 organisms per ml. Both of these might be termed working populations, and present a different picture from populations previously reported for the water in the stream. It must be remembered, however, that this population *acts only on the materials brought into contact with it.* Therefore it is far more functional in the shallow stagnant or semi-stagnant areas below Station F-1011.

These considerations explain in large part the decrease in suspended solids in the few miles below Station F-1011. The decrease in this and other pollution parameters in this stretch of the river is discussed under FJ. CHEMICAL CHARACTERISTICS.

Microbiota of the Fenholloway Estuary and Nearshore Gulf

Originally the Fenholloway was a river whose biotic composition was essentially like that of the Waccasassa and of the Steinhatchee, Econofina, and Aucilla. It was well seeded from its headwater swamps and quiet reaches, and despite its brown water, had a pH of about 7.0 ± 0.2 The hundred or more species recorded in 1953-54 constituted a richer microbiota than found in the Waccasassa and might be termed a typical stream group. What is left in the river today is above the entrance of the cellulose mill waste or in the tributary streams. At times of flood when dilution is great, a few algae and protozoa can be found. Otherwise only bacteria are left.

These bacteria, curiously, include very few filaments of *Sphaerotilus natans,* which is usually common in American streams receiving paper and pulp wastes. There are almost no anaerobic flagellates either, although an occasional individual may be found at the lowest estuary station which also contains at times a few *Beggiatoa* filaments. The most characteristic bacterium is a large oval cell about 3×2 microns in dimensions, very motile, and with no visible inclusions, i.e., it is not a sulfur bacterium. It is present at all times, being especially abundant at the last three estuary stations, but only a few persist at Stations F-1 and F-2. It is not included in the listed bacteria.

The Fenholloway Estuary is obviously a barren, unlovely body of water. Neither the estuary nor its immediate environs in the Gulf support any substantial fish life, whereas it formerly was a good bass stream and good for redfish in the winter. Yet the dilution beyond the deleterious effects are not ordinarily observed beyond Stations F-1, F-2, F-3, F-4, and sometimes F-10. The oyster reefs (Plate III) appear to be dead, and seaweeds (attached algae) do not grow at or inside the oyster reefs. However, both fish and crabs have been seen, and seaweeds and grasses grow near the platform 4340 yards (about 2.5 miles) southwest of Station F-1. Very large numbers of plankton organisms are sometimes found beyond the oyster reefs and also occasionally at Stations F-1, F-2, and F-3.

In 183 samples from the river, estuary, and offshore stations, 484 species of bacteria, algae, and protozoa were taken into account in the biotic studies and these occurred 4077 times. This is a large number, and since the estuary stations were practically barren of all except bacteria, most of these organisms were recorded from offshore. The river receives the organic load of cellulose mill waste, the treated sewage from several thousand people, and other organic wastes as described under FH. SANITARY SURVEY. It should be an enriched water when it enters the Gulf, either from a retained organic load or an abundance of mineral fertilizer from the rapid degradation of its organic load. By comparison the Waccasassa should have a much lower fertility. Yet the number of species in the Waccasassa for a comparable period was 428, only 56 less than in the more widely sampled Fenholloway, and the number of occurrences for these 428 species was 5394, or 1317 more.

No tables are given showing the total numbers of individual species in the Fenholloway studies. They would be too voluminous for this report. But certain species did occur in significant numbers. Using the previously accepted definition of a bloom, 500 per ml, only one ciliate, *Cyclidium,* reached bloom numbers; 4736 per ml at Station F-2 on April 21, 1964, and 824 at the same station on November 17, 1964. The blooms of colorless organisms are easy to account for. They all occurred in areas where they found large bacterial populations on which to feed. *Cyclidium* was the only large organism (25 microns), although *Lembus pusillus* frequently occurred in excess of 100 per ml at Stations F-1 and F-2.

Blooms of photosynthetic organisms are much more difficult to account for. All of them in this study were small, the diatom *Campylosira* being the largest. Unidentified green cells *Chlorella* and probably *Nannochloris* were Chlorophyceae; *Synura, Chromulina,* and *Chrysochromulina* were Chrysophyceae; *Rhodomonas* belonged to the Cryptophyceae; and *Campylosira, Chaetoceras,* and probably *Detonula* and *Skeletonema* were diatoms.

It would normally be expected that bacterial degradation of the river wastes and subsequent degradation of the bacterial cells would result in high PO_4-NO_3 values and that large numbers of green plants would result. The paucity of macroscopic algae and grasses at Stations F-1, F-2, F-3, and F-10, where most of the microscopic green blooms were found, removes the possibility of competition for mineral fertilizer in this area. Yet the chemical results for these areas do not support the idea of a well-fertilized water. Actually the chemical results are difficult to interpret because the first exploratory analyses (July 29, 1963) showed very high NO_3 in the river. It was, therefore, a reasonable assumption that the Gulf stations would show considerable amounts of NO_3.

Since the existence of an abundant biota in a water mass is primarily dependent on available phosphorus (orthophosphate) and nitrogen, it is evident from the numbers found in the nearshore Gulf stations that the supply of these two fertilizing elements is at times high. Figures FJ-9 and FJ-10 seem to confirm this, but these are for total organic nitrogen and total phosphorus. While the ratios are about 2N to 1P, they do not provide an idea as to the total available orthophosphate, nor do they indicate that available nitrogen might be the limiting factor to organism development. Since the figures obtained are generally higher than those for natural waters and since N:P ratio is close to 2:1 instead of 16:1, the conclusions under FJ. CHEMICAL CHARACTERISTICS that most of the phosphorus is present in the microorganisms seem valid.

Despite the fact that the cellulose mill waste is a high carbonaceous waste, it was anticipated that the Fenholloway Estuary would have a larger population of algae and protozoa than the Waccasassa. Such was not the case. Populations were seldom high, although some of the blooms were. *Chlorella* was present at Station F-3 on October 26, 1964, as high as 23,500 per ml.

The study of the microbiology of the Fenholloway has demonstrated that originally the river received an adequate seeding to develop a sizeable population of microbiota and that such a population no longer exists in the river or in the estuary, which now contain only bacteria and some fungi.

It appears, however, that substances toxic to microbiota in the estuary decrease rapidly after discharge to the Gulf, since nearshore Gulf stations exhibit what may be termed a normal biota. The nearshore biota is regarded as directly comparable to that of the Waccasassa both in kind and number. However, there are more distinctly salt water organisms in the Fenholloway nearshore Gulf stations. This might be expected since there is little chance for any of the organisms from upstream stations to reach the Gulf, even if they might be tolerant of salinities encountered there. From a sanitary engineering standpoint, it seems that even in the period of flow in the river the bacteria assimilate much of the waste and are themselves assimilated at the river mouth, where the only demonstrable recovery effect is the large population of ciliates and zooflagellates ringing the river mouth, and referred to above. Table FF-1 illustrates this. Whether the blooms of photosynthetic organisms are a response to possible added nutrients is a moot question. Blooms of *Rhodomonas, Skeletonema,* and *Detonula* have been found in areas distinctly *not* polluted.

Table FF-3

THE NUMBERS OF SPECIES AND OCCURRENCES OF CERTAIN MICROSCOPIC ORGANISMS IN THE WACCASASSA AND FENHOLLOWAY RIVERS AND THEIR ESTUARIES

Organism Group	Waccasassa		Fenholloway	
	Genera or Species	No. Occurrences	Genera or Species	No. Occurrences
Bacteria, various	2	9	6	
Bacteria, sulfur	5	28	10	
Blue-green algae	13	33	16	
Green algae, Chlorophyceae	9	245	13	
Green algae, Volvocales	20	228	20	
Euglenophyceae, green	14	108	31	
Euglenophyceae, colorless	39	354	18	
Chloromonadida	6	54	3	15
Cryptophyceae	10	533	10	251
Chrysophyceae	21	203	15	68
Coccolithophora	2	3	2	5
Dinoflagellata	39	354	49	662
Bacillarieae, diatoms	71	1907	78	1212
Silicoflagellata	2	9	2	6
Zooflagellata	51	877	39	270
Rhizopoda	33	78	24	61
Ciliata	84	538	71	348
TOTALS	421	5561	407	2898

Comparison of Fenholloway and Waccasassa Microbiotas

Table FF-3 is a list of the 15 groups of microbiota and the number of times they were noted in 215 Fenholloway River, Estuary, and nearshore Gulf samples. The figures in this table are slightly different from some others reported herein because a few samples were not considered elsewhere in this report, while certain others are included here for the first time.

The 215 Fenholloway samples included 41 from the river or headwater creeks, which are therefore regarded as fresh water. Only 45 of the named organisms have not been recorded from brackish or salt water. These are:

Chlorophyceae	5
Volvocales	6
Green Euglenophyceae	22
Chrysophyceae	3
Bacillarieae (diatoms)	1
Rhizopoda	3
Ciliata	5

All others have been recorded from salt or brackish water while alive. A much longer list of those not heretofore found in fresh water could be made, as well as a longer list of those tolerating both types of water. Evidently any estuarine situation can be seeded either from fresh water or by invasion from the ocean.

There were only 13 Chlorophyceae in all the Fenholloway samples. Since there are a great many species of this group in fresh waters, it is evident that they adapt poorly to salt water. The same is true of Volvocales and green Euglenophyceae. In each of these groups a few species may become abundant in estuarine water.

If Table FF-3 is compared with Table F-1, a great deal of similarity is seen. The number of samples on which the tables are based is 215 and 221 respectively for the Fenholloway and the Waccasassa. The number of occurrences is widely different, 2898 and 5561 respectively, and this is indicative of the somewhat more restrictive conditions in the lower Fenholloway. Six groups showed considerable differences. Of these, the Fenholloway showed 10 sulfur bacteria versus 5; 31 green Euglenophyceae versus 14; and 49 Dinoflagellata versus 39. These last may be due to the more open water (oceanic) off the Fenholloway mouth. The green Euglenophyceae are attributable to more occurrences in headwaters fertilized by the wastes of Perry and environs. Conversely, the sulfur bacteria differences are indicative of a greater organic and inorganic sulfur content.

Nine of the groups are close together in the number of species and genera encountered. This does not mean that the same organisms are found in each situation. For example, *Gomphosphaeria aponina* is frequent and abundant in the Fenholloway area but virtually lacking in the Waccasassa. But in the Volvocales, almost the same occur, and the same species, *Pyramidomonas grossi,* is dominant in both estuaries. The same is true for the Cryptophyceae where *Rhodomonas* is the dominant. The diatoms, many of them planktonic salt water forms, appear to be ubiquitous; largely the same species occur although their frequency of occurrence is much greater in the purer Waccasassa waters.

For the two Gulf areas and their estuaries it appears that the warm, clear, shallow waters, well fertilized by comparatively large amounts of land drainage, encourage numerous species and sometimes large biotas. The precise effects of organic pollution can immediately depopulate the polluted area, but in the long run the pollution becomes a fertilization resulting in a cycle of living organisms normal for the area.

FG. PRIMARY PRODUCTIVITY

Introduction

Primary productivity estimates in the Fenholloway area were begun in the spring of 1964 and continued for approximately one year. The pollution from the kraft mill wastes is so extensive that the river and estuary no longer contain viable phytoplankton. In areas which are devoid of this type of organism, photosynthesis does not occur. These statements apply to the entire Fenholloway Estuary from its mouth at Station F-1 to the upper limit of the tidal influence above Station F-106. Productivity experiments were therefore restricted to stations in the adjacent Gulf waters where dilution of the wastes from the estuary proper permitted photosynthesis to take place. The location of the Gulf stations are shown on Figure A-5 and on Plate III.

In the adjacent Gulf area only a few *in situ* productivity experiments were completed. Logistics adequate for the completion of experiments of this kind could not be attained mainly because a combination of tidal periods and shallow depth (see Plate III) was such that light and dark bottles could not be incubated *in situ* for the proper length of time required for accurate results. After a few preliminary trials with the *in situ* method, it was found necessary to carry out these estimates in the laboratory.

Productivity determinations carried out in this way showed the relative fertility of water collected at the estuary mouth (Station F-1) and offshore Gulf Stations F-2 through F-11. Photosynthetic differences due to light penetration and turbidity could not be determined in this manner, and no approximation could be made of the productivity *in situ* except infrequently.

The success of the laboratory studies depended upon the collection of samples from Station F-1 and all Gulf stations during a particular cruise. Only in this way could

Table FG-1

PRIMARY PRODUCTION AT STATION F-1 AND GULF WATERS ADJACENT TO THE FENHOLLOWAY ESTUARY

Date		**Station**										
1964		F-1	F-2	F-3	F-4	F-5	F-6	F-7	F-8	F-9	F-10	F-11
6/8	S*	-	1198	-	-	62	108	60	96	-	168	-
6/8	B*	-	715	-	-	-	135	-	99	-	150	-
6/24	S	-	496	59	-	22	17	-	19	-	119	-
6/24	B	-	-	-	-	65	62	-	35	-	139	-
8/26	S	-	1318	707	-	564	964	-	453	-	635	-
8/26	B	-	-	-	-	20	105	-	26	-	60	-
9/22	R†	-	-	-	-	-	554	730	614	600	-	-
10/28	R	-	147	76	-	60	-	-	58	-	60	-
11/17	R	760	502	610	581	466	489	219	200	424	598	178
1965												
1/22	R	18	6	18	-	42	10	-	18	-	16	-
2/9	R	6	18	27	42	24	18	5	17	10	34	24
3/2	R	764	406	537	-	-	380	-	214	-	200	-
3/11	R	13	198	249	207	199	162	83	87	202	907	-
4/1	R	36	235	111	98	55	60	145	156	280	427	42

*S = approximately one foot below surface; B = approximately one foot above bottom.

†R = relative photosynthesis.

NOTE: Values are in mgC/m^3/day (milligrams of carbon per cubic meter per day).

fertility relationships be established. This had the advantage that during a single cruise samples for chemical analysis, microbiological examination, and productivity could be collected at the same time and integrated information obtained.

Productivity and Fertility. Table FG-1 shows the distribution seasonally of phytoplankton production in the study area. Three *in situ* estimates of algal photosynthesis range from 17 mgC/m^3/day to 1198 mgC/m^3/day. Both the maximum and minimum occurred in June, 1964.

Results on June 24, 1964, at Stations F-5, F-6, and F-8 indicate inhibition of photosynthesis in surface water. Maximum productivity at these stations was noted in subsurface water. Reduced carbon-14 fixation in surface water probably was due to high light intensity since this factor has been documented by other investigators as depressing metabolic activity of phytoplankton.

Relative photosynthesis studies were carried out from September, 1964, to the end of the project. These results are included in Table FG-1. A graphical presentation of this portion of the data in Figure FG-1 is informative. It may be seen that nearshore stations in all cases except one were more productive than offshore stations. For the purposes of this comparison, offshore stations were arbitrarily chosen. These were F-5, F-7, and F-11. Inshore stations represent those remaining. Average photosynthesis rates from these latter stations were 275 and 176 mgC/m^3/day respectively. Table A-2 and Figure A-5 show the distance of stations from the mouth of the estuary, and Table G-2 the distance from shore.

Waste Toxicity Assay. The effects of water containing the combined wastes from the Buckeye Cellulose plant and the Perry sewage treatment plant (samples obtained at Station F-106) on algal photosynthesis were studied under laboratory conditions at intervals. Dilutions of Gulf water and the above-mentioned estuarine water containing wastes were made in 125 Erlenmeyer flasks and dosed with carbon-14. The flasks were illuminated in a 20°C incubator for 24 hours. Cellular uptake of C-14 above and below a base line of Gulf water served as the indicator of waste effect on microorganisms.

From an examination of Figure FG-2 it may be seen that uptake of carbon-14 by uncontaminated Gulf water was 180 counts per minute. Similarly, fixation of the isotope by microorganisms in the waste water (Station F-106 was only one-third as great (58 cpm). At a dilution of 1:3 (waste water-Gulf water), photosynthesis is greatly stimulated. The photosynthetic rate drops off at a dilution of 1:10, but remains above that of the Gulf water alone to a dilution of 1:300. This effect can be noted from the figure only to a 1:60 dilution.

In eighty-seven per cent of similar experiments, the combined sewage and kraft wastes in water taken at Station F-106 stimulated carbon-14 uptake by microorganisms in Gulf water. Subsequently, trials were carried out with only domestic sewage or kraft waste so as to follow the the effect on phytoplankton. The results from these experments were inconclusive, and consistent results could not be obtained. More work is required to develop a useful assay for the individual wastes.

A third series of experiments was undertaken using *Dunaliella sp.* instead of the naturally contained phytoplankton. This approach also failed, although Gold (19) has reported C-14 assays for vitamin B_{12} using *Cyclotella nana.*

Plant Pigment Levels. The standing crop of phytoplankton as reflected by plant pigments is shown in Table FG-2.

Table FG-2

LEVELS OF CHLOROPHYLL *a* (mg/m^3) IN SURFACE WATER

Stations F-1 through F-11

Station	Distance from Shore (Miles)	Mean	Maximum	Minimum
F-1	0	7.58	19.18	3.19
F-2	0.4	7.83	27.90	1.26
F-3	1.2	6.84	23.84	1.57
F-10	1.4	5.34	12.51	0.96
F-4	1.7	4.10	11.31	0.98
F-9	2.7	4.40	12.79	1.43
F-6	2.8	4.00	11.93	0.38
F-8	4.6	3.90	16.80	1.25
F-5	5.1	3.63	9.05	0.82
F-7	6.3	2.80	4.58	1.19
F-11	9.4	2.26	3.32	1.55

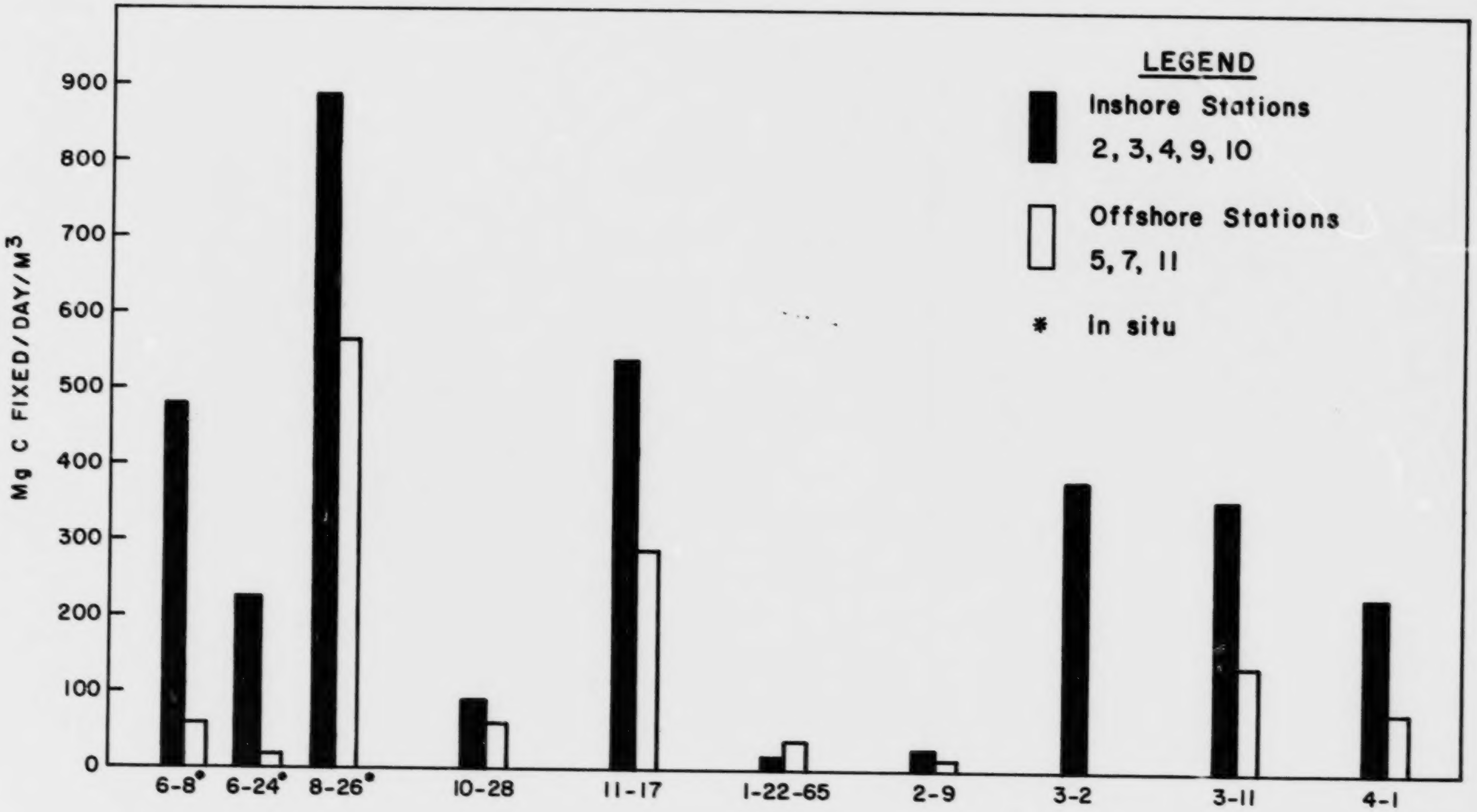


Figure FG-1

Comparative Carbon-14 Uptake in Inshore and Offshore Fenholloway Waters

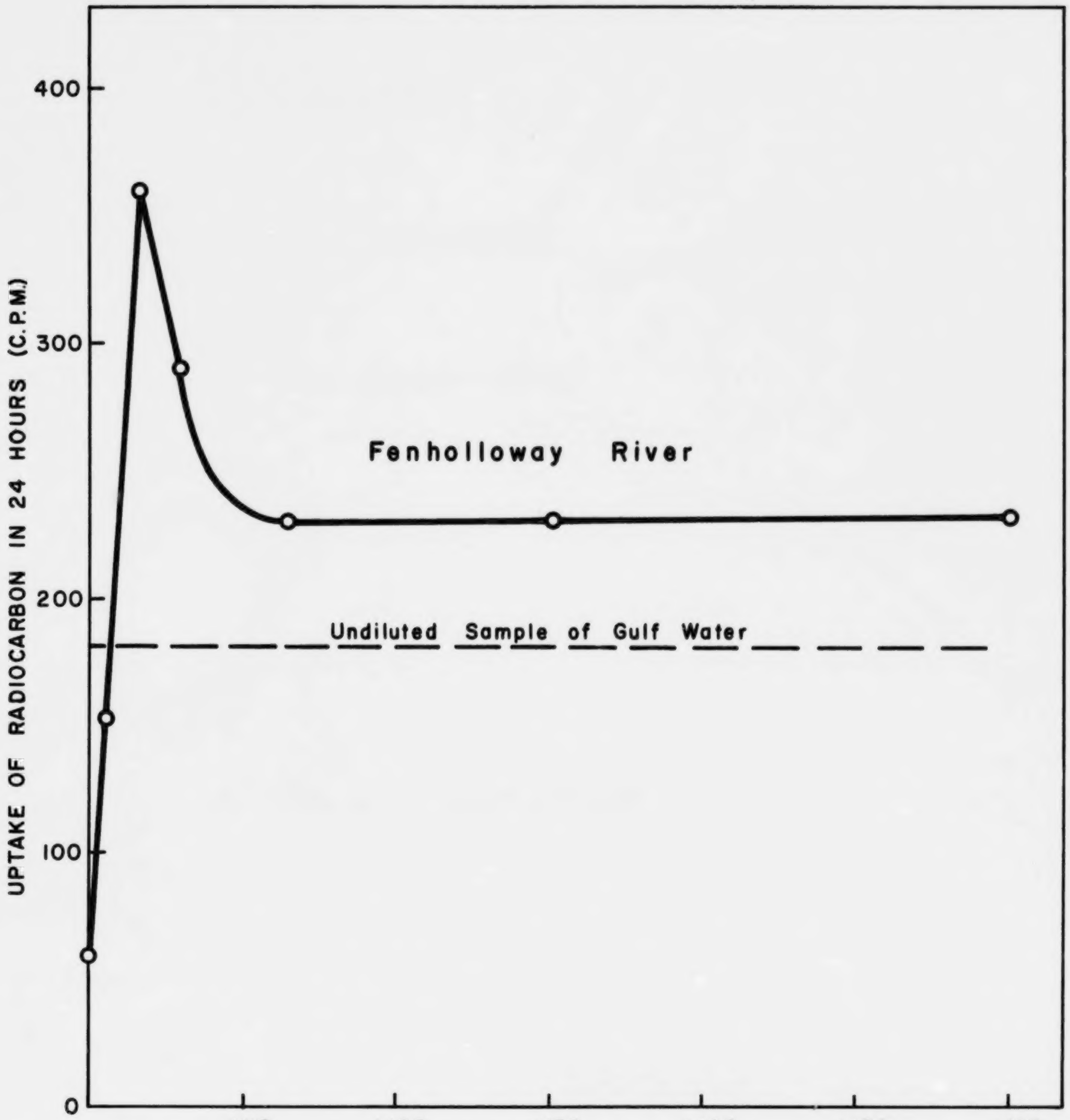


Figure FG-2

Effect of Kraft Pulp Mill & Domestic Wastes
On Phytoplankton Photosynthesis

Mean values of chlorophyll *a* range from 2.26 mg/m^3 at Station F-11 to 7.83 mg/m^3 at Station F-2. The decrease in mean values with distance from land is rather striking and is observable in the maximum and minimum values. In the course of the study, the minimum chlorophyll *a* concentration (0.38 mg/m^3) occurred in January, 1965, and the maximum (27.90 mg/m^3) during April, 1965.

Amounts of chlorophyll *a, b,* and *c* were determined and recorded. The data show that chlorophyll *b* levels ranged from 0.18 mg/m^3 at Station F-3 in April, 1965, to a high of 23.90 mg/m^3 in April, 1964, at the same location.

Some interference was obtained in the analyses for chlorophyll *c*. The difficulty was in unusually high absorbance readings. These came from acetone soluble pigments in non-chlorophyll residues. Nevertheless, chlorophyll *c* varied from 0.21 mspu to 70.43 mspu* at Station F-1.

Distribution of Chlorophyll a. The mean distribution of the standing crop as measured by chlorophyll *a* may be seen in Figure FG-3. Highest levels of plant pigments were found inshore. Decreasing amounts were observed farther out in the Gulf. A concentration of 7 mg/m^3 extended in a band along the shore to the vicinity of Station F-3. Beyond this area of maximum concentration were parallel zones of chlorophyll *a* at 6, 5, and 4 mg/m^3 respectively. All of these isopleths except the one nearshore formed a seaward intrusion toward Station F-5, suggesting a general extension of chlorophyll-bearing material into the Gulf at this location.

Secchi Disk Transparency. The quantity and quality of sunlight penetration into surface water is a major factor affecting the amount of photosynthesis by chlorophyll-bearing plants. Primary productivity within a column of water generally is related to turbidity. Therefore, reduced sunlight penetration in the water leads to similar reductions in integral photosynthesis.

In the Fenholloway offshore waters, transparency is low near the estuary mouth (1-2 feet) and increases gradually farther out in the Gulf where it reaches a maximum of nine feet along a line parallel to Stations F-5 and F-7 as shown in Figure FG-4. This means that productivity of algae and other photosynthetic organisms will be curtailed in subsurface water in the nearshore areas despite the enhanced enrichment of the water. Primary productivity throughout the entire water mass will be highest in zones where light conditions are optimized for photosynthetic processes, even though the water is less fertile than in more turbid areas.

Bioassay of Fenholloway Estuarine and Offshore Waters. Bioassay of these waters was carried out intermittently. Results from samples collected show that during certain seasons phytoplankton growth is limited by insufficient nitrogen and phosphorus (Table FG-3) as in the Waccasassa Estuary. However, at Station F-1 and offshore in the vicinity of the estuary, the nitrate requirements seem to be satisfied early in the summer. This condition may be due in part to the domestic wastes from Perry which are discharged into the estuary water.

Conclusions

The Fenholloway estuary is heavily polluted with

Table FG-3

BIOASSAY OF FENHOLLOWAY OFFSHORE WATERS
SUMMARY RELATING TO NITROGEN AND PHOSPHORUS

Date	*NO_3-N*	*PO_4-P*
3/23/64	0.15	0.47
4/7/64	0.54	0.69
5/8/64	0.28	-
6/25/64	1.21	1.03
8/18/64	0.84	0.99
9/22/64	1.31	1.71
11/17/64	0.86	1.25

Values <1.0 indicate deficiency.

Results reported as ratio of counts per minute, complete medium less NO_3 to complete medium; and counts per minute, complete medium less PO_4 to complete medium.

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*milli special pigment units

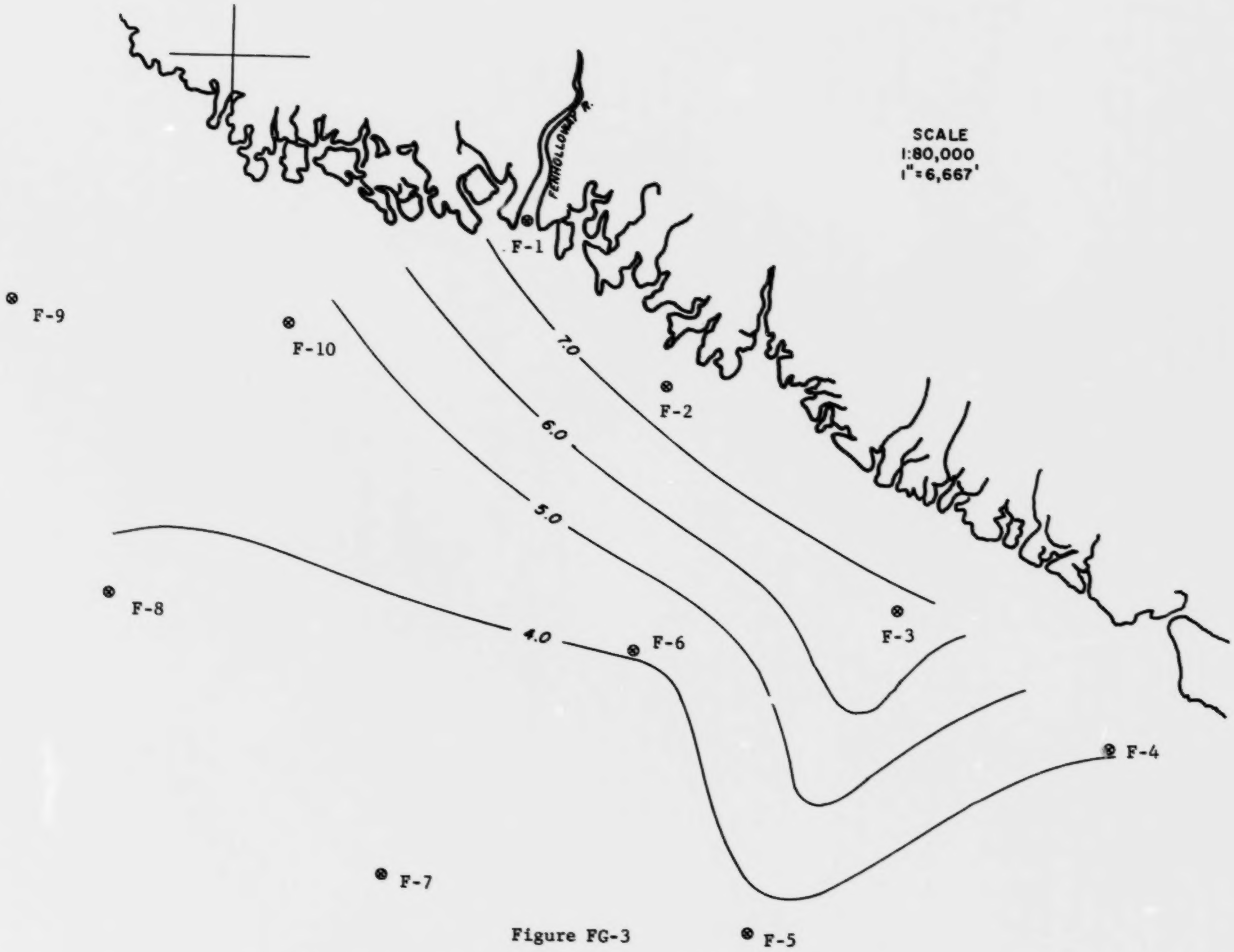
SCALE
1:80,000
1"=6,667'
FENHOLLOWAY R.
F-1
F-2
F-3
F-4
F-5
F-6
F-7
F-8
F-9
F-10
7.0
6.0
5.0
4.0

Figure FG-3

Mean Distribution of Chlorophyll a as mg/m^3 in Surface Water
Fenholloway Estuary 1964-1965

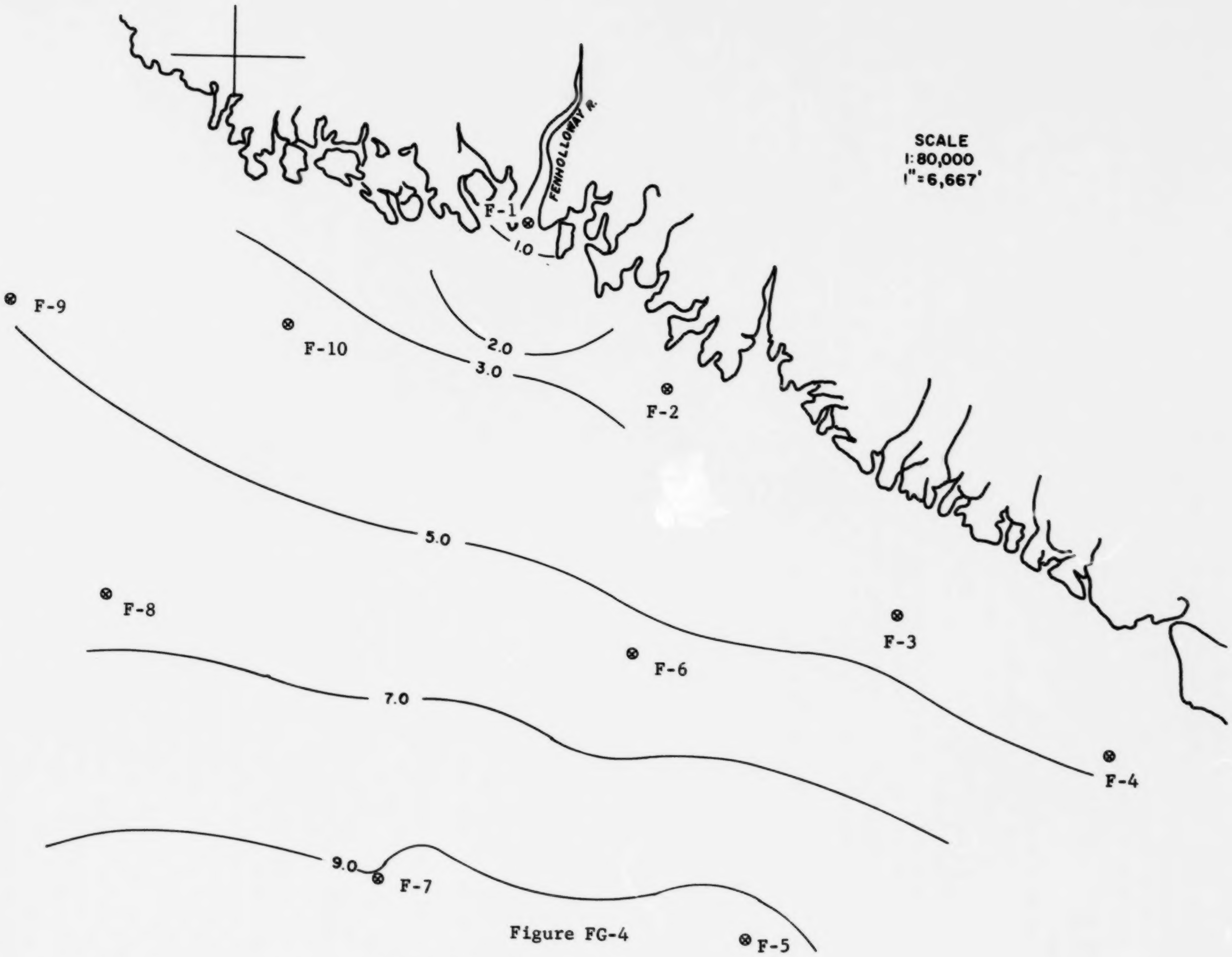
SCALE
1:80,000
1"=6,667'
FENHOLLOWAY R.
F-1
1.0
2.0
3.0
5.0
7.0
9.0
F-2
F-3
F-4
F-5
F-6
F-7
F-8
F-9
F-10

Figure FG-4

Mean Secchi Disk Transparency (Ft.)

Fenholloway Estuary 1964-1965

cellulose mill wastes and to a limited extent with domestic sewage treatment plant effluent. Nutrients in the form of nitrogen and phosphorus enhance the productive potential of the water in the offshore receiving area, particularly from phytoplankton. Estuary water entering the Gulf carries algal nutrients, and water close to shore is more fertile for algal growth than that in the outer Gulf areas. Both chlorophyll *a* and fixation of carbon-14 (laboratory studies) were highest close to shore.

Reduced transparency of the water offsets this relationship, inhibiting photosynthesis in these potentially productive areas by virtue of sunlight attenuation in subsurface water. Although laboratory studies indicate highest photosynthesis close to shore, productive rates in the whole water column should be greatest in outlying Gulf areas where sunlight penetrates more deeply even though nutrient levels are reduced.

FH. SANITARY SURVEY

Human Wastes

The only sewered town in the Fenholloway Basin is Perry, the primary treatment plant of which serves a population of approximately 5000 out of a total estimated population (1964) of 8300. The effluent is chlorinated to a residual of 0.5 ppm and amounts to about one million gallons per day. It is discharged into Spring Creek, which flows into the Fenholloway approximately five miles southwest of Perry and 0.4 mile south of Sampling Station F-103. There is no substantial pollution of Spring Creek by human wastes below the sewage outfall. Toilet wastes from the Metcalf Crab Plant are disposed of through a septic tank with a drain field extending away from Spring Creek.

The pollution which is present in the Fenholloway River above the Buckeye Cellulose mill, as shown by the fecal coliform count at Sampling Station F-101, is almost entirely the result of animal excrement. The area above Station F-101, in which the Fenholloway has its source, is a poorly-drained, mucky bayhead (Figure FB-1) called San Pedro Bay. This area is almost devoid of human habitation.

The only two significant sources of pollution from human wastes on the Fenholloway River from its source to the tidal limits of the estuary are (a) the Buckeye Cellulose Corporation's office, guest houses, and commissary, and (b) the Perry Airport area. Raw sewage from the cellulose mill is discharged into the river just above Sampling Station F-1011. The Perry Airport area was the site of the Perry Air Base during World War II. All facilities at the base were sewered and all wastes treated at that time before they were discharged into the Fenholloway about one-quarter mile below Sampling Station F-102. In this area, which is outside the city limits of Perry, the sewage treatment plant is no longer in use, and at the present time the domestic wastes from a boat building firm, one fraternal organization, and several trailers are emptied into the old sewer lines. These raw wastes are carried through the old effluent line to the Fenholloway. The reports of bacteriological analyses indicate that heavy erratic slugs of human wastes do enter the Fenholloway between Station F-102 and Station F-104. This can only be explained by the occasional clogging and clearing of the old sewage line from the airport area. There is no other substantial source of human wastes discharged to the river.

In the upper part of the estuary there is direct dumping of toilet wastes from one dwelling and from the river operations base of the area crabbers. The first source is approximately one-half mile upstream from Sampling Station F-106 and the second source is from 100 yards above to 200 yards below Sampling Station F-106. The operations base of the crabbers has been expanding since July, 1964.

Animal Wastes

The fecal coliforms that have shown up as the result of animal excrement have been localized to Spring Creek and its tributaries and to that section of the Fenholloway River above Sampling Station F-1011. There are several pastures abutting the banks of Rocky Creek (tributary to Spring Creek) from which animal wastes could originate.

Industrial Wastes

Crab garbage from the Metcalf Crab Plant was used as hog feed and disposed of on land prior to July, 1964. All of this garbage is now dumped into the Fenholloway River at Sampling Station F-104. Industrial wastes from the Buckeye Cellulose mill at Foley which are discharged into the Fenholloway River immediately above Sampling Station F-1011 are described under FI. PHYSICAL, CHEMICAL, AND BACTERIOLOGICAL ANALYSES.

Conclusions

The Fenholloway is moderately polluted from human wastes and heavily polluted by Industrial wastes. The substantial increase in coliforms in 1965 reported in the tables of separate Section L is attributed to the increased organic wastes from expanded operations of the crab plant.

FI. PHYSICAL, CHEMICAL, AND BACTERIOLOGICAL ANALYSES

Introduction

Nearly ten thousand physical, chemical, and bacteriological analyses were carried out on samples collected from river, estuarine, and adjacent Gulf of Mexico locations in the Fenholloway system during the period from January, 1964, through July, 1965.[*] The program comprised routine sampling and extended studies. The latter involved repeated and extensive sampling at various tidal stages and depths at a particular estuarine location. Tables FI-1 and FI-2 are illustrative of the analyses contained in the separate Section L.[†] In the following comments the general chemical and bacteriological characteristics are presented and summarized. A detailed discussion of the chemistry of the Fenholloway River, Estuary, and adjacent Gulf waters is presented under FJ. CHEMICAL CHARACTERISTICS.

The sampling stations employed in the Fenholloway studies are shown on Figure A-5. Station F-101 defines the natural characteristics of the Fenholloway River waters. Station F-1011 reflects the state of the river immediately following discharge of kraft mill effluent (approximately 23 miles above the mouth of the estuary). Stations F-102 and F-104 reflect the influence of this industrial pollution in the fresh water section of the Fenholloway prior to its confluence with Spring Creek. The influence of the flow in Spring Creek, which receives treated sewage effluent from the town of Perry, is determined at Station F-103, just above its confluence with the Fenholloway. Stations F-106, F-1061, and F-107 are located in the Fenholloway Estuary, which is about four miles in length. Station F-106 can be considered generally to reflect the condition at the head of the estuary following the "input" of the polluted fresh water flow. Station F-1 is located in the mouth of the estuary. Stations F-2 through F-11 are in the adjacent waters of the Gulf roughly from two to ten miles from the mouth. Stations F-108 at F-111 are located in the Henderson River tributary system.

Before turning to the chemical and bacteriological data obtained in the study, it is appropriate to call attention to the hydrologic setting in which the sampling program has been carried out. The fresh water flows experienced throughout the 1964-1965 sampling period were generally high in relation to the long-term record. Further, the flows varied over a wide range. For example, daily streamflows to the estuary varied from 230 to 2000 cfs on actual sampling dates. The hydrologic aspects of the Fenholloway study are discussed under FD. HYDROLOGY. The general effects of fresh water flow and also the stage of tide upon physical and chemical parameters are considered briefly in this section and in more detail in other parts of the report.

Chemical Analyses

The same general procedures for sample collection, field determinations, etc. as described in PART I for the Waccasassa studies were followed for the Fenholloway. Determinations of lignins were incorporated in the Fenholloway study because of the presence of kraft mill waste as a primary pollution source. Table FI-3 presents the arithmetic mean values (except as otherwise noted) for twelve different parameters based on routine surface sampling of river and estuary stations.

Fresh Water (River) Section. The data in Table FI-3 warrant two important observations. The first is the major change in water quality due to the introduction of lagooned kraft mill wastes at Station F-1011. A grab sample of the lagooned effluent was taken in July, 1964, and analyzed with the following results:

Item	mg/1	Item	mg/1	Item	Units
Cl^-	328	Total Solids	1500	Color	900
SO_4	333	Volatile Solids	500	Turbidity	130
COD	802	Volatile Suspended Solids	64		
Alkalinity	349	NO_3	0.5		

The second observation from the data in Table FI-3 is the substantial decrease in magnitude of all parameters between Station F-1011 and Station F-106 near the head of the estuary and 26 miles below Station F-1011. Moreover, the larger part of this decrease occurs in the first two miles below Station F-1011, where additional contributions of fresh water flow are not substantial. This phenomenon is discussed in some detail under FJ. CHEMICAL CHARACTERISTICS.

The relatively small amount of suspended solids and lignins which reach the estuary are mostly carried out to the Gulf by the fairly strong fresh water and tidal currents. The apparent increase in suspended solids at some of the Gulf stations noted in Table FI-4 is believed due to bottom sediments put in suspension in the shallow water by the propeller of the sampling boat.

The small influence of the treated sewage effluent from the town of Perry introduced into Spring Creek about five miles above its mouth is indicated by comparison of the data from Stations F-103 and F-104. Actually the dilution afforded to the polluted Fenholloway is beneficial.

The Estuary. The physical-chemical characteristics of the waters sampled at all of the estuary stations were found to be strongly influenced by factors related to tidal stage and direction, depth, and fresh water flow. In inspecting the estuarine routine sampling data for patterns in the typical chemical parameters of pollution, it is apparent that on the whole only relatively small chemical changes occur in the short distance between the tidal

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[*] Analytical procedures for determining physical, chemical, and bacteriological parameters are described in Appendix 2 to this report.

[†] Refer to preface for a list of the separate Section Reports.

Table FI-1

PHYSICAL AND CHEMICAL RESULTS OF ROUTINE SAMPLING

Station F-107

Date 1964	Time	Tide	Depth Samp. (ft.)	Temp. Water °C.	DO		Color Units	Turb. Units	5 day BOD mg/1	COD mg/1	Chloride mg/1	Sal. °/oo	pH	Nitrogen: mg/1			Total PO_4 mg/1	SO_4 mg/1	Alk. mg/1
					mg/1	Sat.%								NH_3	TON	NO_3			
12/16	1000	Tidal stages are given in the separate Section L.	1				450	7		103	71		7.2						
”	1000		7				400	9			70		7.8						
1965																			
1/4	0910		1	16	0	0	300	20		126	320	0.6	7.6	0.05	0.45		0.50		
”	0910		6	16	0	0	160	9		146	7850	14.1	7.4	0.04	0.15		0.40		
1/7	1620		7	20	0	0	140	30		172	2800	5.1	7.8	0.03	0.48		0.60		
1/13	1250		1	15	0	0	205	12		109	2000	3.6	7.3	0.05	0.32		0.40		
”	1300		8	15.5	1.65	18.7	70	4		89	10300	18.4	7.5	0.04	0.30		0.20		
1/22	0730		1	20	0	0	310	14		185	3133	5.7	7.2	0.04	0.55		0.30		
”	0745		7.5	13.5	5.83	61.5	160	8		103	9625	17.2	7.2	0.01	0.35		0.20		
”	1630		1	17	0.60	6.1	280	9		166	3090	5.6	7.5	0.02	0.65		0.40		
”	1635		7	19	6.09	72.0	100	7		71	9882	17.7	7.6	0.01	0.32		0.10		
1/26	1030		1	17.5	0	0	250	4		99	552	1.0	7.3	0.02	0.55		0.08		
”	1035		9	17	1.10	12.3	175	18		157	7420	13.3	7.1	0.01	0.45		0.07		
2/2	1035		1	15	0	0	470	8		141	429	0.8	7.2	0.02	1.15		0.45		
”	1040		4	15	0	0	460	8		165	574	1.1	7.2	0.01	0.85		0.76		
2/8	1510		1	20	0	0	570	12		157	318	0.6	7.5	0.02	0.60		0.67		
2/16	1329		1	14	0.75	7.5	350	10		134	4280	7.7	7.2	0.10	0.65		0.87		
”	1334		9	15	2.04	20.0	240	23		118	6621	11.9	7.3	0.02	1.15		0.55		
3/1	1130		1	16	0	0	250	7		118	3100	5.6	6.8	0.01	1.00		0.36		
”	1150		7	16	0	0					7100	12.7	7.0						
3/5	0825		1	16	0.45	4.5	350	10		101	99		7.1	0.01	0.90	<0.05	0.55		
”	0830		8.5	16	0	0	400	11		87	178	0.4	7.1	0.01	1.00	<0.05	0.72		
3/10	0845		1	15	0	0	450	6		103	75		6.5	0.02	0.58		0.29		
3/15	1022		1	19	0	0	500	13		99	155	0.3	7.1	0.01	0.68		0.74		
3/22	1125		1	16	0	0	490	7		101	300	0.6	7.1	<0.01	0.92	<0.05	0.54	57	124
”	1125		4.5	16	0	0	450	10		108	300	0.6	7.0	0.01	0.72	<0.05	0.62	84	128
3/31	1525		1	23	0	0		5	23		1460	2.7	7.0	<0.01	0.95	<0.05	0.44	228	120
”	1530		10	22	0.20	2.4		7	8		6620	11.9	7.0	<0.01	0.60	<0.05	0.39	960	116
6/23	0830		1	27	0	0	450		>11	122	420	0.8		<0.20	<0.20	0.13	0.97		
”	0830		7	27	0	0	150		3	100	7630	13.7		<0.20	<0.20	<0.05	0.52		
”	1620		1	27.5	1.00	12.5	400		> 7	110	518	0.9		<0.20	<0.20	<0.05	1.04		
”	1625		3	27.5	1.00	12.6	400		7	110	1330	2.4		<0.20	<0.20	<0.05	0.86		

Table FI-2

RESULTS OF BACTERIOLOGICAL EXAMINATIONS

Station F-104

Date Collected	Time Collected	Depth Collected (ft.)	Temp. °C.	S.P.C.	Coliforms MPN/100 ml	Coliforms Fecal MPN/100 ml
3/31/64	1240	1	17	310,000	>110,000	230
4/27	1230	1	24	64,000	230,000	<3,600
5/4	1255	1	22	350,000	43,000	3,600
6/1	1640	1	26	240,000	110,000	2,900
6/15	1745	1	28	30,000	240,000	43,000
6/22	1550	1	28	34,000	460,000	21,000
8/10	1420	1	27	33,000	43,000	<3,600
8/17	1405	1	27.5	100,000	3,600	<3,600
8/20	1645	1	26	1,500,000	460,000	240,000
8/24	1740	1	28	650,000	460,000	150,000
3/29/65				470,000	>1,100,000	>1,100,000

Station F-106

Date Collected	Time Collected	Depth Collected (ft.)	Temp. °C.	S.P.C.	Coliforms MPN/100 ml	Coliforms Fecal MPN/100 ml
4/7/64	0840	1	24	290,000	>110,000	110,000
4/27	1115	1	24	120,000	210,000	<3,600
5/6	1210	1	22	43,000	23,000	3,600
6/1	0930	1	25.5	140,000	110,000	46,000
6/15	1700	1	27	51,000	150,000	300
6/22	1505	1	26	58,000	1,100,000	43,000
6/29	1525	1	26	950,000	460,000	<360
8/10	1330	1	26	100,000	23,000	<360
8/17	1300	1	27	44,000	2,300	<360
8/20	1520	1	26	360,000	460,000	7,500
8/24	1645	1	27	500,000	93,000	4,300
2/16/65	1225	1	16.5	680,000	>1,100,000	150,000
"	1230	6	17	910,000	>1,100,000	120,000

Station F-1061

Date Collected	Time Collected	Depth Collected (ft.)	Temp. °C.	S.P.C.	Coliforms MPN/100 ml	Coliforms Fecal MPN/100 ml
8/10/64	1300	1	26	120,000	23,000	<3,600
8/17	1225	1	27	45,000	4,300	<360
8/20	1445	1	26	400,000	93,000	9,300
8/24	1630	1	29	470,000	23,000	9,300
2/16/65	1247	1	17	760,000	>1,100,000	7,500
"	1252	8	16.5	510,000	>1,100,000	240,000
3/15	0958	1	18	520,000	9,300,000	9,300,000

Table FI-3

CHEMICAL PARAMETERS AT FENHOLLOWAY RIVER AND ESTUARY STATIONS

ARITHMETIC MEAN OF SURFACE SAMPLES

Station	DO % Sat.	BOD mg/1	COD mg/1	Chlorides mg/1	Color Units	Turbidity Units	pH	SO_4 mg/1	Total PO_4 mg/1 ‡	TON mg/1	Lignins P.B. †	Sus. Solids mg/1 †	Notes
F-101	55	2.6	154	8.3	775	7	5.3	27	0.23	0.95	9	5	River
F-1011	0	130	1390	292	2190	83	7.6	148	1.34	2.13	88	59	River
F-102	0*	80	376	112	930	58	6.9	90	0.84	2.25	24	20	River
F-104	0*	51	262	72	675	29	7.2	60	0.74	1.47	20	18	River
F-103	59	2.3	47	16.8	190	5	7.6	23	0.49	0.30			Spring Creek
F-106	0†	24	130	61	457	21	7.3	62	0.40	0.60	6	16	Head of Estuary
F-1061	0†	20	136	70	458	11	7.3	-	0.40	-	6	-	
F-107§	4	15	123	920	419	11	7.2	214	0.42	0.78	12	14	Junction, Henderson River
F-1§	23.5	10	111	3520	320	9	7.3	458	0.35	0.77	12	3	Estuary Mouth

*Values reached 20 during mill shutdown period.

†Values reached 30 during mill shutdown period.

‡Weighted average from Table FJ-6.

§Values for these stations, while accurate, may be misleading due to the wide range in magnitudes.

Table FI-4

SUSPENDED AND VOLATILE SOLIDS AND LIGNIN

Fenholloway Stations

		March 5, 1965				March 22, 1965				March 31, 1965				December 9, 1965			
Station	Miles	Sus. Solids	Vol. Solids	Lignin (Hach)	Flow cfs	Sus. Solids	Vol. Solids	Lignin (P.B.)	Flow cfs	Sus. Solids	Vol. Solids	Lignin (P.B.)	Flow cfs	Sus. Solids	Vol. Solids	Lignin (P.B.)	Flow cfs
F-101		22	20	7.5	Streamflow at F-103 + F-104 = 800 cfs	5	2	9	Streamflow at F-103 + F-104 = 790 cfs				Streamflow at F-103 + F-104 = 420 cfs	0	0		Streamflow at F-103 + F-104 = 270 cfs
F-1011	0	108	108			59	50	88		246		144		226	199		
F-102	1.6	48	40	20		20	13	24						261	139		
*SH361	3.6													28	-		
F-104	9.9	12	4	15		18	14	20						15	15		
F-106	20.3	22		10		16	12	6						12	12		
F-1061	21.2	24		7.5		10	10	6									
F-107	22.1	46		5.0		14	14	12		15		7		13	13		
F-1	22.7	34		10		3	6	12		33		12		32	-		
F-2	24.7									3		1		9			
F-10	25.2									8		1		18			
F-6	26.6									6				6			
F-9	27.9									15		1					
F-3	27.9									7		1					
F-8	28.1									22		0.9					
F-7	29.1									11		0.8					
F-5	29.7											0.6		33			
F-4	30.4											0.6					
F-11	32.1											0.6		21			

*Bridge on State Highway 361, between Stations F-1011 and F-102.

Table FI-5

ARITHMETIC MEANS – SURFACE SAMPLES

(Routine Sampling Data)

Station	Distance Miles	Salinity ppt	DO % Sat.	BOD mg/l	COD mg/l	Color Units
F-1	0	6.4	23.5	10	111	320
F-2	2.0	17.6	77.2	2.1	62*	104
F-10	2.5	17.1	79.6	2.1	61	110
F-6	3.9	23.1	92.6	1.4	45	43
F-3	5.2	18.7	85.7	1.5	63*	62
F-9	5.2	19.1	85.8	1.6	44	89
F-8	5.4	22.4	88.2	1.3	40	49
F-7	6.4	25.1	87.9	1.2†	34	27
F-5	7.0	25.2	86.8	1.3	44	31
F-4	7.7	20.2	83.9	1.3	47	60
F-11	9.4	23.3	90.0	1.4	47	27

*Disregarding analysis of 1-22-65
†Disregarding analysis of 3-31-65

limit (above Station F-106) and the mouth of the Fenholloway. For example, dissolved oxygen values at surface depths are either zero or quite small all along the Fenholloway Estuary at low tidal stage. The appreciable dissolved oxygen observed occasionally at higher stages of the tide is the result of more nearly complete vertical mixing. As detailed under FE. TIDAL PHENOMENA, vertical inhomogeneity is at times pronounced in the Fenholloway Estuary. Inspection of Table FI-3 gives only an approximately correct impression of the changes in quality in the estuary proper, i.e., from Station F-106 to Station F-1. The values for chloride indicate the influence of partial mixing of fresh and saline waters upon surface sample data. See also Figures FE-2 and FE-3. The relatively strong influence of Gulf water is revealed by the appreciable average dissolved oxygen concentration at Station F-1, the mouth of the estuary. The station averages are derived, of course, from data obtained under varying streamflow, tidal, and meteorological conditions. Thus surface DO at Station F-107 varies from zero to 32 per cent saturation with an average of 4 per cent.

In summarizing the physical and chemical profiles of the Fenholloway River and Estuary, it can be said that the data obtained show extensive reduction by various mechanisms in the concentrations of organic pollutants over the distance of about twenty miles between the kraft mill waste discharge and the upper end of the estuary. The residual BOD at Station F-106 ranged from about 30 to 60 mg/l under conditions of lower fresh water flow (200-300 cfs) and were from 1 to 10 mg/l under flood flow conditions (up to 2000 cfs). In general, average reductions in BOD, COD, volatile solids, turbidity, and lignins were five- to ten-fold, with average flow dilutions of only about two- to three-fold.* These generalizations are derived from sampling data obtained during estuary streamflows ranging from 230 to 2000 cfs and under conditions of temperature ranging from about 14 to 30°C.

Adjacent Gulf Waters. Physical and chemical data were obtained in routine sampling at eleven stations in the adjacent waters of the Gulf of Mexico. Examination of the data in relation to information on both the fresh water flow and the tidal stage reveals that these factors have a considerable influence, as do also wind intensity and direction. With these factors kept in mind, a reasonably accurate impression of the concentration patterns in these offshore waters can be gained by referring to arithmetic mean values of some of the parameters shown in Table FI-5.

The mean values indicate a general radial dispersion in the adjacent waters of the pollution discharged from the estuary. There is, however, an indication in these data of some tendency for the pollution to be present in greater concentrations at Stations F-3 and F-4, which are southeast of the estuary mouth. Data for Stations F-2 and F-10 suggest that the initial dispersion (two-three miles) tends to be symmetrical. The data for salinity, DO, color, and COD at Stations F-3 and F-4, in comparison with those from Stations F-9 and F-5, show somewhat less mixing of the estuarine and Gulf waters in the area close to the eastern shore than in the western and southern areas of the Gulf adjacent to the estuary. The effect is a relatively small one and is in qualitative agreement with the observed tidal currents described under FE. TIDAL PHENOMENA. A radial dispersion model as discussed under FK. DIFFUSION AND POLLUTION ASSIMILATION may thus be considered as a reasonably good approximation to the observed phenomena.

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*See also Table FJ-1.

It is necessary to suggest a possibly needed qualification with respect to the chemical oxygen demand data obtained in the more saline waters at the Gulf sampling stations. As described in Appendix 2 to this report, it cannot be assured that the COD data obtained for samples of high salinity are quantitatively correct. It seems correct to consider that these particular data for COD are all too high because of significant positive interference from chloride. It is likely, therefore, that the means for COD data may be too high by some 10 to 50 mg/1. The *relative* magnitudes should be viewed as only generally indicative.

Bacteriological Analyses

The small numbers of total bacteria (median 940) and of coliforms (median MPN/100 ml 930 total and 36 fecal) at Station F-101 indicate slight pollution from animal and soil sources. However, organic matter of all kinds prevalent in the Fenholloway River from Station F-1011 to the Gulf is a sufficient substrate to support a wide spectrum of bacterial species in large numbers. With the addition of the raw sewage from the pulp mill outfall immediately above Station F-1011, the bacterial species increase in number and biomass. Substantial augmentation undoubtedly occurs in the area between Station F-1011 and F-102 because (a) the initial decomposition of a great deal of organic waste is accomplished in this tortuous swampy section of the river, and (b) these products become food for bacteria that do not attack the cellulose wastes.

The further addition of raw sewage from the Perry Airport area downstream from Station F-102 and the crab garbage from the bridge at Station F-104 also increases the number and biomass of bacterial species. Standard coliform tests in this case can serve only to indicate the gross contamination of the water in the main stream of the Fenholloway below Station F-1011. In these reaches total counts exceed 1,000,000, and MPN/100 ml for total and fecal coliforms also exceed 1,000,000.

Review of the data fails to reveal any anomalies which might be difficult to explain. However, it should be kept in mind that the differences in streamflow occasioned not only by wide ranges in precipitation but also by the flushing mechanism employed by the Buckeye Cellulose Mill as previously described under FD. HYDROLOGY are responsible for wide ranges in dilution and the resultant differences in bacterial counts. It should also be kept in mind that the bacteriological samples taken were grab samples subject to the influence of slugs of pollution and to the influences of the tide.

Station F-103, which is located on Spring Creek, reflects the presence of the treated effluent from the Perry sewage treatment plant five miles above. The counts obtained here were appreciably lower than those found in the main stream of the Fenholloway from the pulp mill to the Gulf.

The highest bacterial pollution is found at Henderson River stations. These reach at times an MPN/100 ml of over 4,000,000. This is due to the upstream movement of polluted Fenholloway Estuary water during flood tides. This pollution tends to accumulate in the Henderson River areas since there is very little fresh water discharge to assist in flushing during low tide. No substantial pollution originates in the Henderson River area.

Bacterial counts are drastically reduced as the result of dilution and diffusion in the offshore area. Beyond Stations F-2 and F-10 bacterial contamination is very small or virtually absent.

FJ. CHEMICAL CHARACTERISTICS

Introduction

The chemical characteristics exhibited at various locations in the fresh water, estuarine, and nearshore waters of the Fenholloway system are the resultant of chemical interactions between and mixing of the unpolluted waters of the drainage basin, the various organic and inorganic components of a kraft mill waste effuent, the effluent from a domestic sewage treatment plant, other organic wastes, and the saline waters of the Gulf of Mexico. The chemical properties of the estuary and nearshore Gulf waters are thus expected to depend upon the volumes of fresh water flow, the strengths and character of the industrial and domestic waste effluents, and the influence of tidal action on the flushing and mixing action of the estuary system. In addition to hydrologic and tidal factors, the action of winds upon the movement of water masses in the relatively small Fenholloway Estuary can at times be expected to exert a strong influence upon the chemical characteristics of the waters at a particular sampling station. Routine and extended sampling covered the period January, 1964, to March, 1965. Some special sampling was performed later in 1965.

Characteristics of Unpolluted Fenholloway River Water

The Fenholloway has its origin in San Pedro Bay, a relatively high swampy area. The water as indicated by samples from Station F-101, located upstream from sources of pollution (Figure A-5), contains highly colored organic acids characteristic of the drainage area. Color typically ranges from 100 to 1000 units. The alkalinity at Station F-101 is usually small or zero, with pH values ranging from roughly four to six. Waters of this kind can be expected to contain considerable soluble iron, perhaps in combination with the colored organic acids. The total solids of the Fenholloway unpolluted natural waters are generally low and on the order of 100 to 200 mg/l.

The waters of the Waccasassa are not normally as highly colored as those of the Fenholloway. In times of very heavy rainfall and runoff, the color of the Waccasassa waters may approach that of the Fenholloway under normal conditions. As far as can be judged from the available data at Station F-101, there is more nitrate present than at corresponding locations in the Waccasassa and its tributaries. On the other hand, there is little or no detectable inorganic phosphorus in evidence in the headwaters of the Fenholloway. As much as 0.1 mg/l PO_4 was observed frequently in the waters of the Waccasassa. There is a small amount of apparently organic phosphorus present at Station F-101 in the Fenholloway.

Thus while similar in a number of ways, there are a few recognizable differences between the chemical properties of the natural Fenholloway waters and those of the Waccasassa. The former contains more organic matter, is more intensively colored and less alkaline, and seems to have less inorganic phosphorus and more nitrate than the latter.

Characteristics of Typical Kraft Mill Waste Effluent

Wood for pulping operations typically consists of 40-50 per cent cellulose, 15-25 per cent other polysaccharides, 30 per cent lignin, and 5 per cent minerals, sugars, fats, resin, and protein (8). Accordingly, the liquid effluent from a kraft mill is expected to contain wood sugars (five-carbon and six-carbon), lignins, hemicellulose, tall oil soaps, organic sulfur compounds, sulfides, and sulfates. The alkalinities of kraft mill effluents typically should be on the order of several hundred mg/l. The color of kraft mill waste is usually quite high. The five-day BOD of a typical effluent can by 200-300 mg/l. An analysis of a grab sample of the lagooned waste effluent from the kraft mill on the Fenholloway is given in the preceding section of this report.

The Pearl-Benson reaction[*] was applied to samples of lagooned effluent from the kraft mill in November, 1964. Indulin C, a nearly pure lignin provided by a West Virginia Pulp and Paper Research Laboratory, was employed as a standard in order to obtain a rough estimate of the amount of lignin-like material in the waste effluent. With the Pearl-Benson procedure it was estimated that about 50 mg/l of soluble lignin material was in a particular sample of effluent. In view of the foregoing enumerated chemical characteristics of kraft waste effluents, one would expect that the carbohydrate components would be readily biochemically oxidized, thus exerting a strong demand upon available oxygen resources. Other organic components in addition to the sugars may also be more or less readily oxidized, e.g., soaps and organic sulfur compounds. It is generally recognized that lignins may be quite resistant to biological oxidation. Among the other expected effects of kraft mill waste effluent discharge to a stream are increases in stream color, sulfate, chloride, and nitrate concentrations. However, nitrate and sulfate may be reduced by readily oxidizable organic substrates. Appreciable quantities of phosphorus are common in kraft waste effluent either in organic or inorganic form. See Table FJ-6.

Domestic Waste Treatment Plant Effluent

The treated effluent from the town of Perry, Florida, (Figure A-5) is discharged to Spring Creek, a major tributary of the Fenholloway. The plant effluent has a BOD of about 50 mg/l. This leads to a BOD of 2-5 mg/l in Spring Creek at its confluence with the Fenholloway under low (about 100 cfs) streamflow conditions. The dissolved oxygen of Spring Creek at this point is typically about 50-60 per cent of saturation. Relatively few measurements of phosphorus were made in Spring Creek. The orthophosphate in the Perry plant effluent on April 13, 1964, was six mg/l, a reasonable value. In June, 1964, the orthophosphate in Spring Creek near the confluence with the Fenholloway (Station F-103) was 0.06 mg/l. Measurements in the spring of 1965 of total phosphates at Station F-103 showed an appreciable contribution, on the order of 0.5 mg/l. Spring Creek also averaged 24 mg/l sulfate at Station F-103, probably of natural origin.[*] The streamflow of Spring Creek is somewhat less than that of the Fenholloway at the confluence. With a low BOD and a relatively high dissolved oxygen level, Spring Creek cannot be considered a seriously polluted stream at its mouth. It would not normally exercise an overly adverse effect on the quality of the natural waters of the Fenholloway. Under existing conditions Spring Creek provides favorable dilution of the polluted river as indicated in Table FI-3.

Chemical Characteristics of Gulf of Mexico Waters[†]

The general characteristics of the deeper waters of the Gulf of Mexico are reasonably familiar: salinity of

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[*] Described in Appendix 2 to this report.

[*] Hampton Springs water contains 440 to 557 mg/l of sulfate, reported in Water Research Paper No. 6, Chemical Character of Florida's Waters, by A. P. Black and Eugene Brown. State Department of Conservation, 1951.

[†] See also under J. CHEMICAL CHARACTERISTICS of the Waccasassa for a further discussion of *Salinity in the Gulf.*

30 °/oo or greater with corresponding chloride concentrations; sulfate concentrations of approximately 2200-2400 mg/1; a pH of about 8.0; an alkalinity of about 120 mg/1; and rather low color, BOD, phosphate, and nitrate. However, salinity determinations of Gulf waters in the vicinity of the Waccasassa and Fenholloway estuaries have values which indicate an appreciable amount of dilution by fresh water flows. Figure J-10 indicates nearshore waters of less salinity in the vicinity of the Fenholloway Estuary than those near the Waccasassa Estuary. This is probably explained by the low fresh water flows in 1963 when most of the Waccasassa analyses were made and the higher fresh water flows in 1964-1965 when most of the Fenholloway analyses were made. The long-term record at Cedar Key indicates the large variations in salinity which are typical of these nearshore Gulf waters.

The Influence of Kraft Mill Waste Pollution on Chemical Characteristics of the Fenholloway

From the sampling programs carried out on the Fenholloway River and Estuary during 1964 and 1965, numerous chemical data are available which indicate the pronounced influence of a single pollution source, a kraft mill effluent, on the characteristics of this stream. For example, Figure FJ-1* presents longitudinal profiles of COD, BOD, dissolved oxygen, color, and salinity obtained on four dates in June, 1964. The fresh water flow to the estuary was in the range of 230-300 cfs for all of the profiles. The mill waste effluent enters the stream at Station F-1011. A large increase in BOD and COD in the stream below this point is evident, along with a concomitant drop in the dissolved oxygen level from about three mg/1 to zero. Reappearance of dissolved oxygen in the Fenholloway occurs in the estuary chiefly as a result of the tidal inflow of the relatively oxygen-rich Gulf waters, as evidenced by the general correspondence of the salinity and dissolved oxygen profiles. The BOD and COD of the stream decrease progressively as a consequence of organic decomposition, dilution by increased streamflow, and possibly the settling out of suspended organic solids. The latter process may be particularly important near the mouth of the estuary where large deposits are visible at low tide, as indicated on Plate III under FC. HYDROGRAPHY. On the other hand, the bottom of the estuary from Station F-106 to Station F-107 is chiefly bed rock which is kept free from sediments by the scouring action of river and tidal flow.

Profiles of sulfate, chloride, and total phosphate for the river and estuary were obtained on March 22, 1965, and are represented in Figure FJ-2. Samples were collected at surface depths. The fresh water flow to the estuary on this date was 875 cfs. The diagrams for Station F-103 (Spring Creek) and Station F-104 (Fenholloway) give an impression as to the relative contributions of the two streams to the inorganic chemical parameters represented. The influence of the mixing of fresh and salt water in the estuary is also evident.

The major influence of the kraft mill effluent (introduced to the stream at Station F-1011 upon the phosphate and sulfate concentrations in the Fenholloway River and Estuary is apparent from the data in Figure FJ-2. Chloride concentrations in the upper section of the river are also seen to be increased considerably by the waste effluent. Since chloride is known to be a conservative tracer, a qualitative comparison of the profiles for sulfate and total phosphate with the chloride profile is of some interest. There is some evidence that both of the former substances are being removed to a small extent in the fresh water section of the river, i.e., above Station F-106.

In Figure FJ-3 profiles of parameters of organic pollution sampled on the same date are presented. The parameters are COD, total organic nitrogen, lignin determined by the Pearl-Benson Method, color, and volatile suspended solids. With the exception of the values for color, these parameters of organic stream pollution show strikingly the influence of mill waste discharge on stream quality. Data on dissolved oxygen concentrations for this date showed 60 per cent of saturation at Stations F-101 and F-103 (Figure A-5), with zero oxygen at all stations on the Fenholloway between the effluent discharge and the mouth of the estuary, where mixing of fresh and saline waters lead to the presence of small oxygen concentrations. From these profiles and other analytical data it is concluded that considerable physical and/or chemical removal of organic pollutants takes place in the river for some distance below the point of waste discharge. Quantitative conclusions are made difficult because of likely transients in effluent quality and quantity.

Color is seen to be increased in the river by several hundred units as a result of the mill waste discharge. However, when reaching Station F-104 the color of the river is roughly the same as before the introduction of the waste. The natural color of the Fenholloway is thus apparently a rather good semi-quantitative tracer of river flow. The total color measurement is not specific, being influenced by turbidity and the presence of the highly colored kraft lignins. The Pearl-Benson lignin profile, on the other hand, reveals that the natural coloring matter of the drainage area to a large extent differs from the coloring matter in the waste effluent. It is also apparent that filterable lignins are decreased in the passage of the waste flow downstream, as indicated in Table FJ-1. This observation raises a question about the suitability of the lignins as a tracer for waste dispersion studies.

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*Where distances in miles from the mouth of the estuary (Station F-1) are used in Figures of this section, negative values are distances up the estuary and river. Positive values are Gulfward.

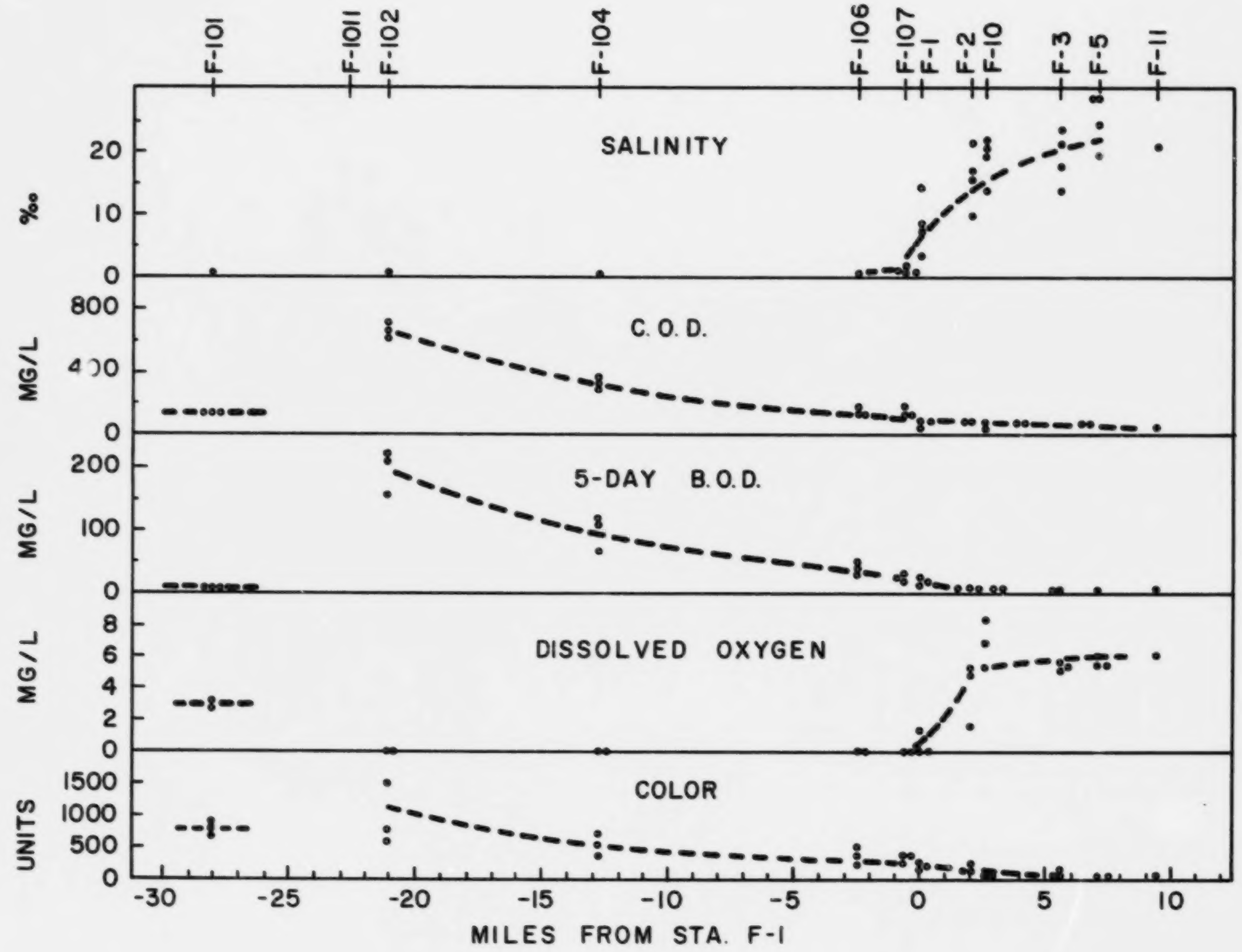

Figure FJ-1

Longitudinal Profiles of Surface Salinity, Chemical Oxygen Demand, Biochemical Oxygen Demand, Dissolved Oxygen, and Color on Four Sampling Dates in June 1964.

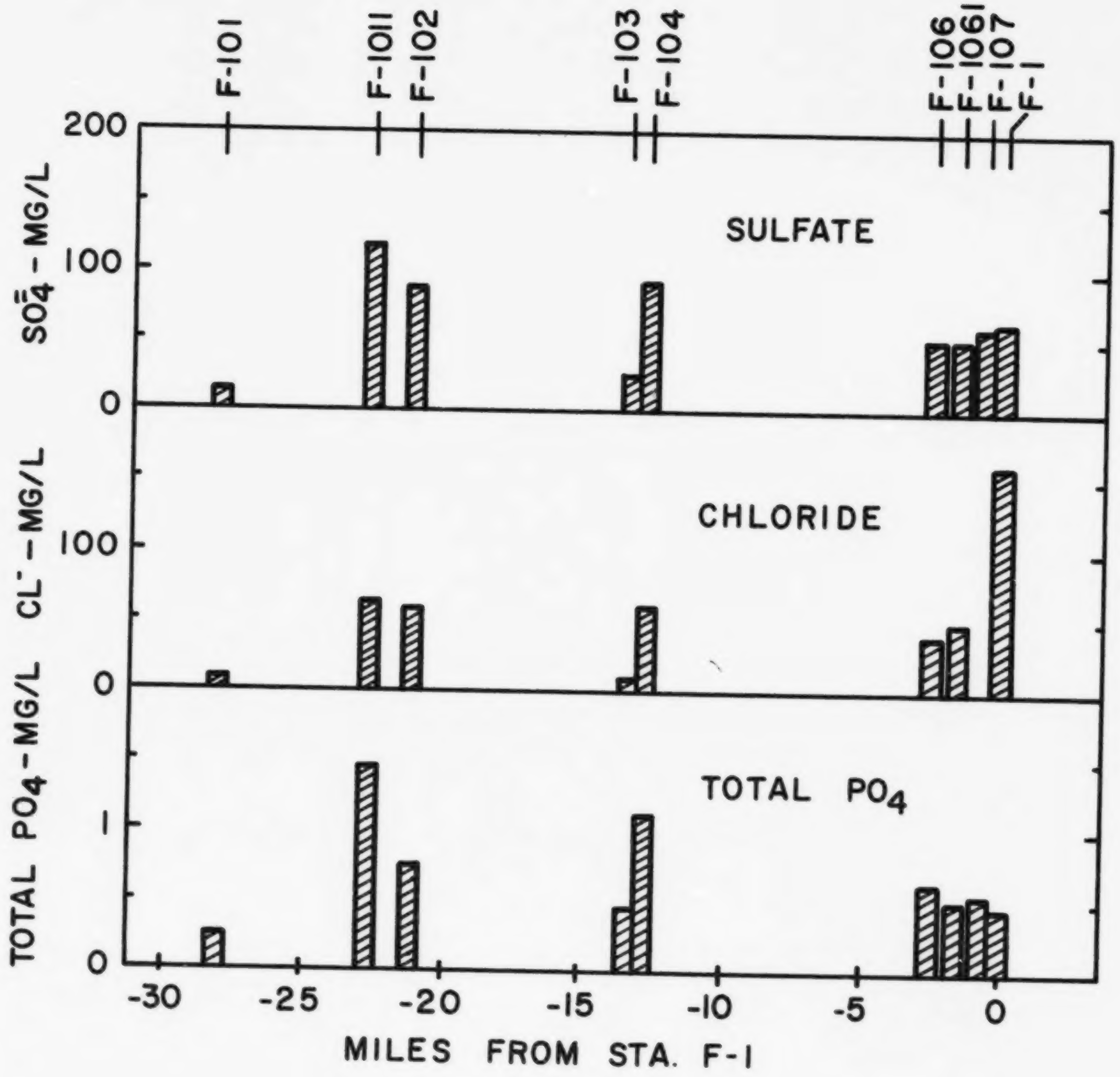

Figure FJ-2

Longitudinal Profiles of Sulfate, Chloride, and Total Phosphate, March 22, 1965.

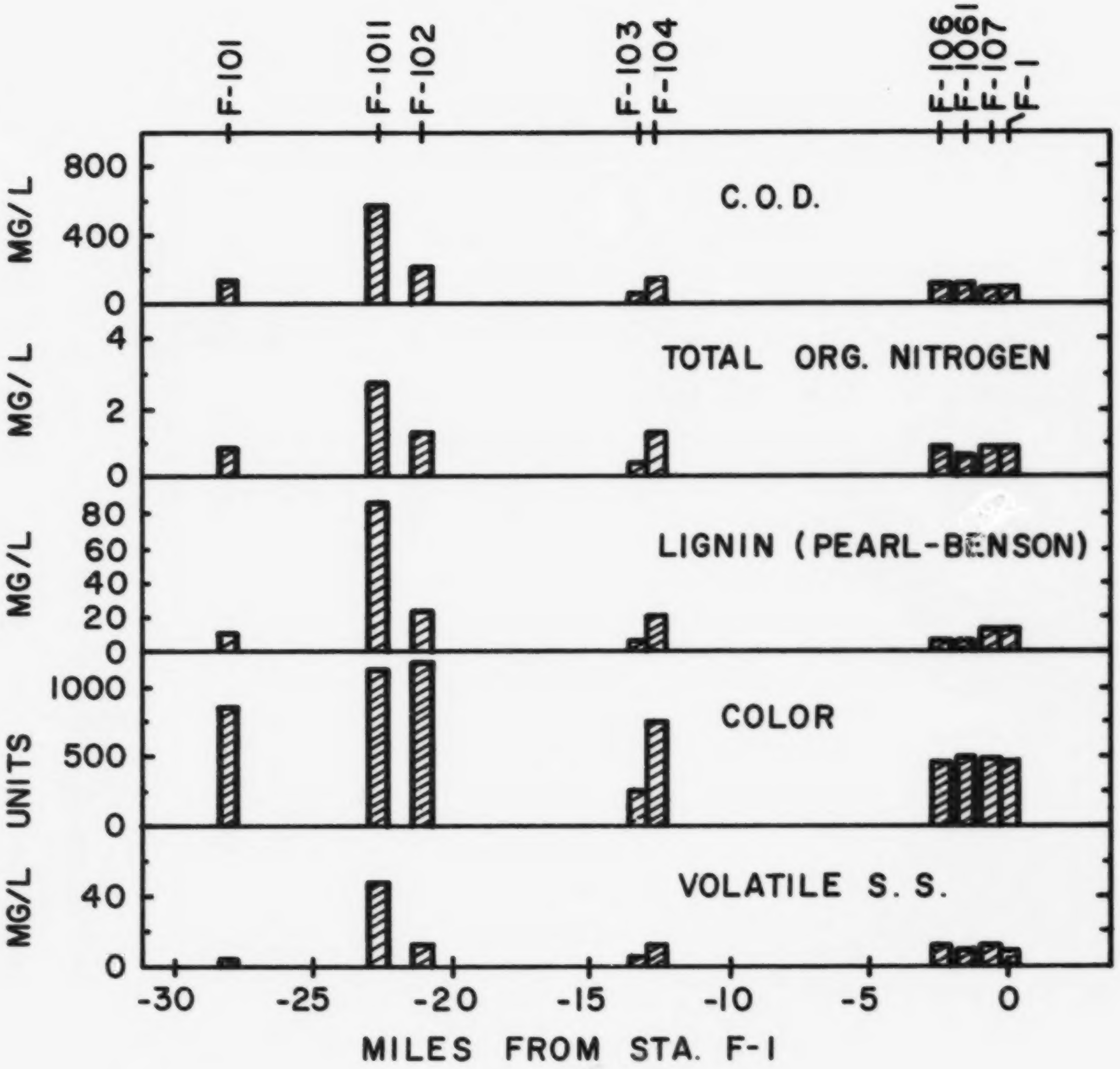

Figure FJ-3

Longitudinal Profiles of COD, Total Organic Nitrogen, Lignins, Color, and Volatile Suspended Solids, March 22, 1965.

Decrease in Pollution Parameters in River Section

In view of the large amount of materials characterized as lignin and lignin derivatives expected to be present typically in kraft mill waste effluents, it was hoped that chemical estimation of lignins by the Pearl-Benson procedure would serve as a specific tracer for the mill waste in its passage through the estuary and into adjacent Gulf waters. The presence of appreciable Pearl-Benson lignin in the mill waste flow and in the Fenholloway throughout its length was confirmed by determination of a profile (Figure FJ-3) for the river and estuary. Note that Station F-103 is on Spring Creek. The Pearl-Benson procedure appeared to distinguish rather well between natural coloring substances in the fresh water flow and lignin materials in the waste.

In connection with the discussion of Table FI-3 in the preceding section, reference was made to the rapid decrease in certain pollution parameters with passage downstream from Station F-1011 to the head of the estuary near Station F-106. Examination of Tables FI-3, FI-4, FJ-1 and of Figure FJ-3 indicates an especially rapid decrease in lignins and suspended solids in the 1.6 miles between Stations F-1011 and F-102 and a continued decrease in lignins and other parameters between Stations F-104 and F-106. An investigation of these phenomena produced interesting conclusions.

Referring to Table FJ-1, it will be noted that the decrease in concentration of lignins and suspended solids is much greater than can be accounted for by dilution from increased streamflow as one proceeds downstream. Thus on March 22, 1965, lignins are reduced 3.7-fold and 15-fold at Stations F-102 and F-106 respectively, while fresh water flow increased only slightly at Station F-102 and about two-fold at Station F-106. A similar situation occurred with respect to suspended solids.

Influence of Terrain. In the 1.6 miles between Stations F-1011 and F-102 and for a few miles farther the Fenholloway River flows through a wide swampy area where the velocity of flow is markedly reduced by dense swamp growths. The stream braids out into shallow embayments and ponded areas. The gross effects of the debris-clogged areas are to settle out much of the suspended matter and to provide a lodgment for bacterial slimes onto which it can be adsorbed. The solids are then subject to microbial degradation. This situation has been more fully described under FF. MICROBIOLOGY.

Influence of pH. Information supplied by Dr. William J. Nolan, head of the College of Engineering Pulp and Paper Laboratory, indicates that lignins are rapidly precipitated from kraft mill lagoon wastes when the pH gets below 8. From Table FI-3 it will be observed that the average pH at Station F-101 is 5.3. This increases to 7.6 at Station F-1011 after the introduction of the wastes and decreases to 6.9 at Station F-102. There seems little question that substantial amounts of lignins are precipitated in this reach of the river and for a few miles below. Residual lignins continue to be precipitated during the remaining course of the river until it discharges to the estuary. As indicated in Table FJ-1 and as would be expected, the decrease in lignins and suspended solids between Station F-1011 and Station F-107 during the low flow of March 31 was greater than during the higher flow of March 22, since velocities were less and time for precipitation and sedimentation was greater.

Table FJ-1

DECREASE OF LIGNINS AND SUSPENDED SOLIDS VERSUS INCREASE IN FLOW

Station X	Date	Lignins mg/l	Ratio Sta. F-1011 / Sta. X	Suspended Solids mg/l	Ratio Sta. F-1011 / Sta. X	Estimated Flow cfs	Ratio Sta. X / Sta. F-1011
F-101	3/22/65					209	
	3/31/65	9		5		93	
F-1011	3/22/65	88	1	59	1	404	1
	3/31/65	144	1	246	1	202	1
F-102	3/22/65	24	3.7	20	3	450	1.1
F-104	3/22/65	20	4.4	18	3.3	505	1.25
F-106	3/22/65	6	15	16	3.7	795	2.0
F-107	3/22/65	12	7.3	14	4.2	875	2.2
	3/31/65	7	21	15	16.4	465	2.3

Influence of Dilution. Below Station F-104 a substantial increment of streamflow comes from Spring Creek.

Conclusions. The foregoing discussion seems to explain satisfactorily the combination of factors responsible for the rapid decrease in various pollution parameters between Station F-101 and the head of the estuary near Station F-106. It seems clear that due to these factors lignins cannot be considered to be conservative tracers of kraft mill wastes on the river section of the Fenholloway. In the offshore waters, lignin concentrations seem to coordinate reasonably well with other parameters indicating a predominantly radial distribution beyond the mouth of the estuary.

Mill Shutdown Period

For approximately ten days (August 9-19, 1964) the operations of the kraft mill were interrupted. Sampling data obtained on August 17, 1964, reflect the influence of residual pollution from the preceding mill waste effluent discharge upon a number of chemical parameters in the Fenholloway River. Table FJ-2 shows the effect of mill shutdown on BOD, COD, and DO values at stations in the upper section of the river under a relatively narrow range of fresh water flows. While organic pollution is still evident, it is at a significantly reduced level. As a result, measurable amounts of dissolved oxygen were observed at Station F-102 (1.6 mg/1); Station F-104 (1.6 mg/1); and Station F-106 (2.4 mg/1). Under usual conditions the dissolved oxygen at these stations has been zero except on a few occasions at Station F-106, where high tides and southwest winds can bring about appreciable mixing of oxygen-containing Gulf and river waters. The relatively low DO values generally found at Station F-101 are presumably due to organic matter from the headwater swampy areas. The average and median of all observations were respectively 5.03 mg/1 and 4.70 mg/1.

Influence of Streamflow on Chemical Characteristics

The fresh water flow to the estuary ranged from 230 to 2000 cfs on the dates of sample collection. Table FJ-3 presents data on concentrations of color, COD, chloride, sulfate, and BOD observed at times of different river flows. The sampling stations are located in the fresh water section of the Fenholloway. An increase in runoff leads to an increase in color. The natural color substances of the swampy drainage area are washed and leached out as in high flow regimes on the Waccasassa. The levels of the pollutant parameters are reduced by dilution with increasing flows. On August 13, 1964, the sampling date of highest streamflow, the kraft mill was in the period of shutdown. The effects of this high streamflow are thus superimposed upon the effects of a reduced pollution load.

In the estuarine and nearshore Gulf portions of the Fenholloway system the influence of variation in runoff on chemical parameters is qualitatively similar to that observed in the fresh water section. Because of the mixing of fresh and saline waters in the estuary, it is necessary to compare observations made under similar tidal conditions. Observed concentrations of chloride and color at the same sampling stations under different fresh water flow conditions are presented in Table FJ-4. The data are merely illustrative since other factors such as wind, density currents, and vertical mixing affect the distribution of fresh and salt water. Further, while color is a kind of tracer for fresh water, it has been noted earlier that the amount of color increases with increased runoff. Qualitatively, however, one can notice the effect of high runoff in displacing or over-running saline water. Qualitatively similar relationships are observed for samples taken near bottom depths at Station F-107. The effects of depth and tidal stage upon concentrations of chemical parameters are discussed below and have already been examined with respect to salinity intrusions under FE. TIDAL PHENOMENA.

Influence of the Estuarine Circulation on Chemical Parameters in the Fenholloway

The important role of the estuarine circulation in establishing the vertical and longitudinal distributions of physical, chemical, and biological properties of the estuarine waters has already been emphasized in connection with the studies made on the Waccasassa Estuary. Studies of various chemical parameters in the Fenholloway have confirmed that the tidal influence is pronounced there also, although the upstream extent of tidal action is shorter in the Fenholloway than in the Waccasassa. As mentioned under FE. TIDAL PHENOMENA, the tidal patterns of the Fenholloway Estuary are generally similar to those of the Waccasassa. On the Fenholloway the vertical stratification is greater, the ebb tide velocities are higher, and the flushing time is shorter than on the Waccasassa.

The changing shape of vertical salinity profiles with tidal stage is evident in Figure FJ-4, which shows data obtained in an extended study made at Stations F-107 and F-1 on February 4, 1965.* The fresh water flow to the estuary was 375 cfs. Incomplete vertical mixing is pronounced during high water stages at both stations. Mixing approaches completeness near low water stage when considerably lower average salinities are present.

The influence of tidal stage upon dissolved oxygen and chloride concentrations for different depths at Station F-107 on September 1, 1964, is shown in Figure FJ-5. The fresh water flow is devoid of oxygen, and the absence

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*See also Figures FE-2 and FE-3.

Table FJ-2

INFLUENCE OF KRAFT MILL OPERATION ON ORGANIC POLLUTION LOADINGS IN THE FENHOLLOWAY RIVER

August, 1964

Date	Estuary Flow cfs	5-day BOD-mg/1			COD-mg/1			DO-mg/1		
		Station			Station			Station		
		F-101	F-1011	F-102	F-101	F-1011	F-102	F-101	F-1011	F-102
8/6	1175	0.9	196	24	168	711	232	3.80		0
8/10	1350	2.5	202	8	150	779	178	3.77		0
8/17*	1125	4.4	35	10	183	247	174	3.49	0	1.58†
8/20	850		154	42		687	352		0	0
8/24	1300	4.5	190	33	165	720	228	3.53	0	0

*During period of Kraft Mill shutdown, 8/10/64 through 8/19/64.

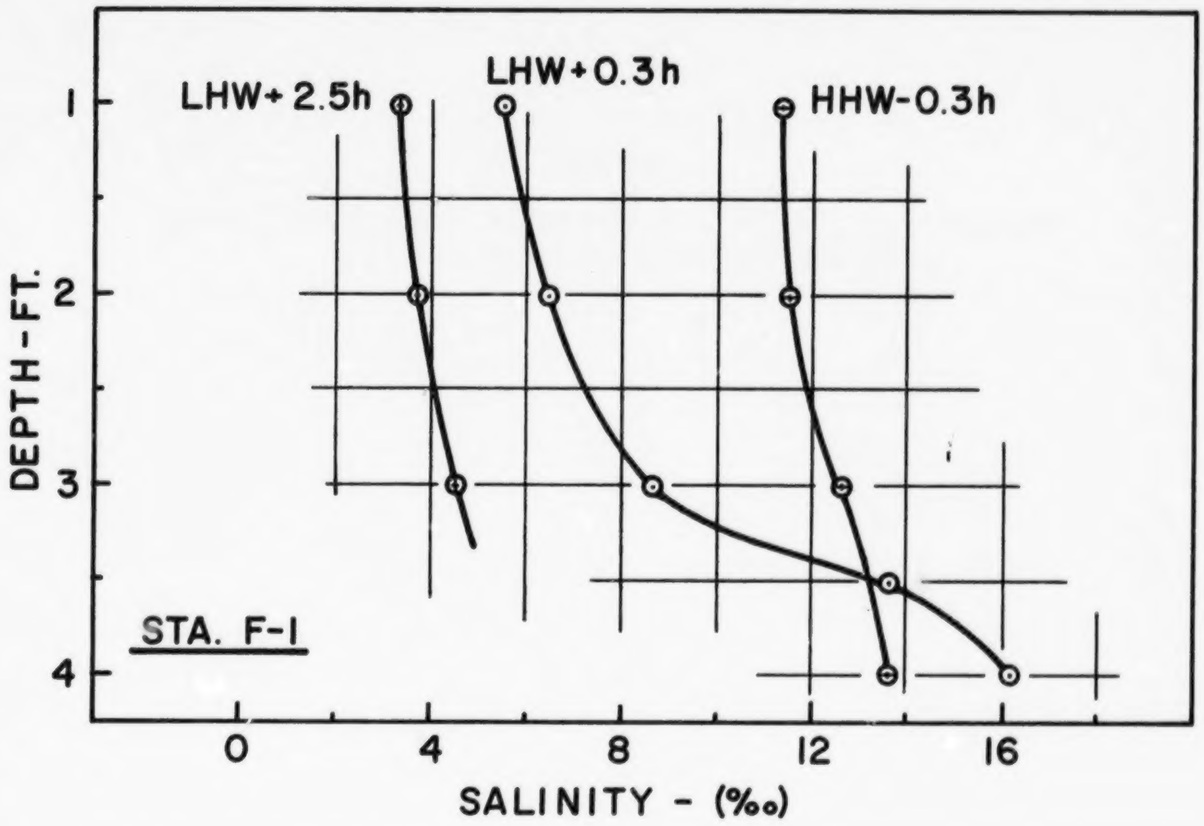
†20 per cent saturation.

Table FJ-3

INFLUENCE OF STREAMFLOW ON CHEMICAL CHARACTERISTICS IN THE FRESH WATER SECTION OF THE FENHOLLOWAY

Date	Estuary Flow cfs	Station	Color Units	COD mg/1	Cl^- mg/1	$SO_4^=$ mg/1	5-day BOD mg/1
6/22/64	230	F-101	700	130	13	41	3.4
		F-102	550	660	194	99	220
		F-104	440	317	117	80	106
8/6/64	1175	F-101	650	168	7	10	0.9
		F-102	680	232	57	67	24
		F-104	650	172	39	16	15
8/13/64*	2000	F-102	575	193	74	59	15
		F-104	625	135	25	22	3.3
3/22/65	875	F-101	875	122	6	12	
		F-102	1175	205	60	87	
		F-104	750	154	60	90	

*Kraft mill shutdown.



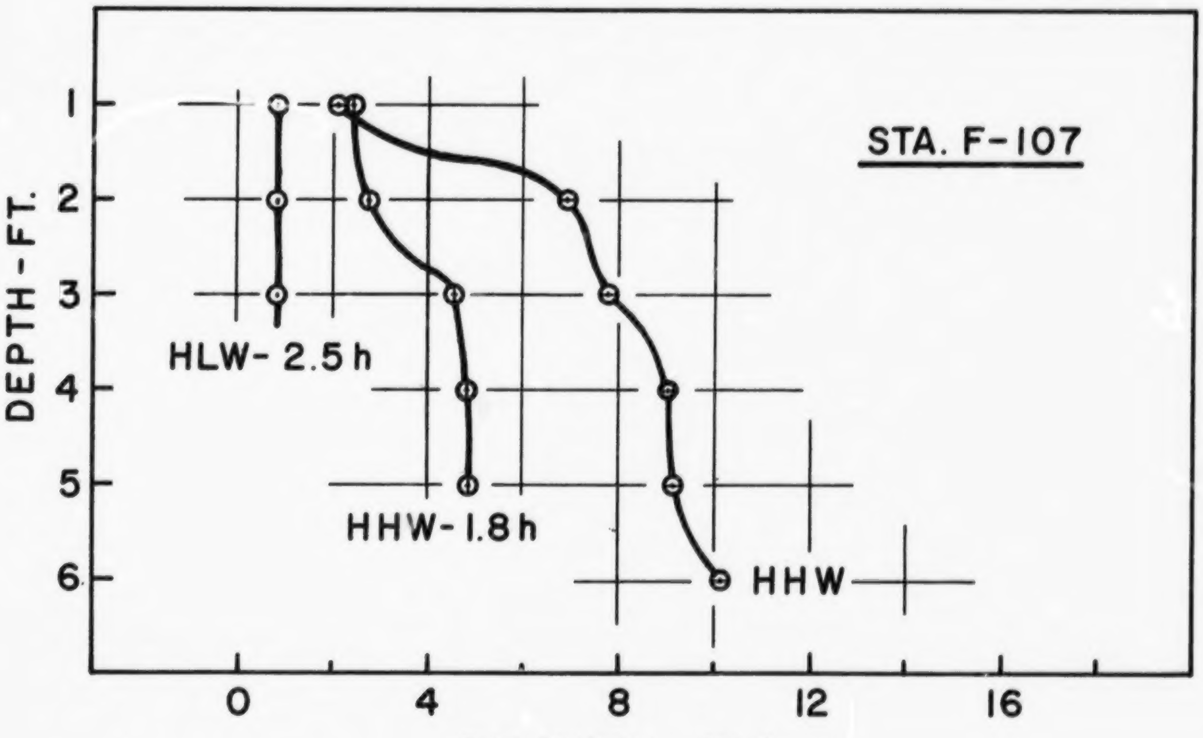


Figure FJ-4

Vertical Distributions of Salinity Observed at Stations F-1 and F-107 on February 4, 1965.

Table FJ-4

INFLUENCE OF QUANTITY OF FRESH WATER FLOW ON CHLORIDE CONCENTRATIONS AT FENHOLLOWAY ESTUARY STATIONS* UNDER COMPARABLE TIDAL CONDITIONS

Date	Fresh Water Flow to Estuary cfs	Station	Tidal Stage	Chloride mg/l	Color Units
9/1/64	630	F-107	HHW	1075	-
8/17/64	1150†			158	-
1/4/65	360	F-107	LLW	320	300
8/13/64	2000†			39	800
1/26/65	335	F-107	LHW	552	250
3/10/65	535			75	450
6/29/64	300	F-1	HHW	4100	150
5/6/64	1300			90	500
1/26/65	335	F-1	LHW	1169	255
3/10/65	535			149	400
6/22/64	230	F-2‡	HHW	9000	85
8/17/64	1125†			6240	240
6/22/64	230	F-10‡	HHW	12,000	43
8/17/64	1125†			8600	140

*Surface samples

†Period of mill shutdown

‡Nearshore Gulf station

of oxygen in the surface water at high and low water stages indicates that the fresh water is flowing over the salt water. The stratification is particularly pronounced at high tide. The phenomenon of incomplete mixing at the same station is also reflected in concentrations of BOD observed at different depths.

Concentrations of dissolved oxygen, salinity, and color as affected by tidal stage and depth are shown for Stations F-1 and F-107 in Figure FJ-6. Fresh water flow to the estuary was 375 cubic feet per second. Winds were relatively constant N or NE. The dissolved oxygen and salinity "trace" the saline water, while the color is representative of the fresh water flow. Data were not obtained at bottom depths for Sample D because of the small depth involved at low tide.

Additional data concerning chemical concentrations as a function of tidal stage and depth are presented in Figure FJ-7. Samples were collected on January 22, 1965, at surface and bottom depths at approximately two hours after and two hours before HHW and LHW respectively. Fresh water flow to the estuary was approximately 290 cfs. At Station F-1 in the mouth of the estuary, stratification appears less pronounced preceding lower high water than following higher high water. Dissolved oxygen was apparently influenced by surface aeration at the times of sampling. However, the concentrations of oxygen are rather small (about 15 per cent saturation) in all cases. At Station F-107 the stratification of fresh and salt water is clearly reflected in significant differences between surface and bottom concentrations of all parameters at both of the tidal stages of sampling.

Chemical Character of Tributary Tidal Streams

Slough and Cut-Off Creeks and Henderson River are small tidal streams which enter the Fenholloway near Stations F-1061 and F-107 respectively (see Figure A-5).

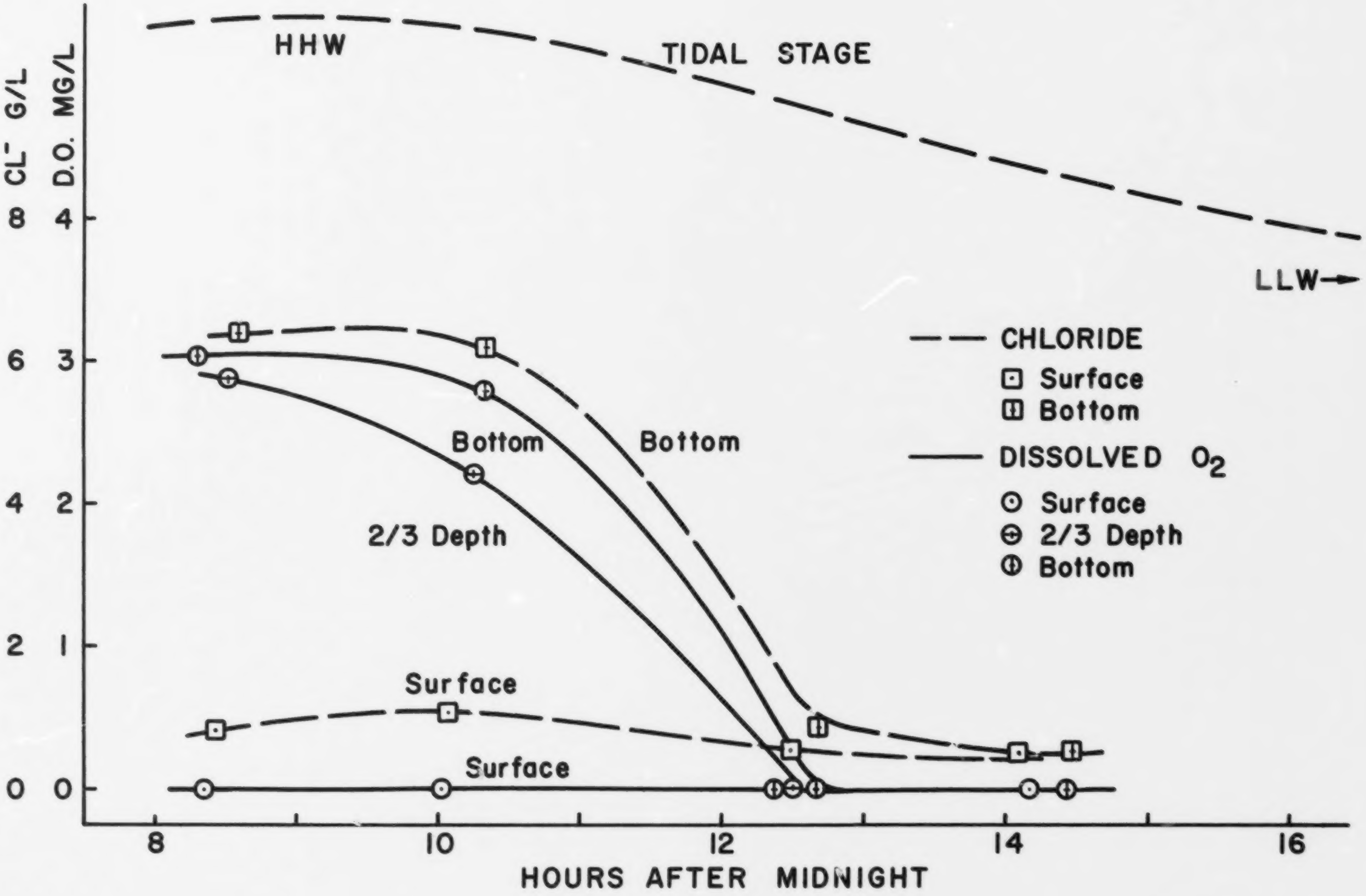


Figure FJ-5
Influence of Tidal Stage Upon Dissolved O_2 and Cl^- Concentrations at Different Depths at Station F-107, September 1, 1964.

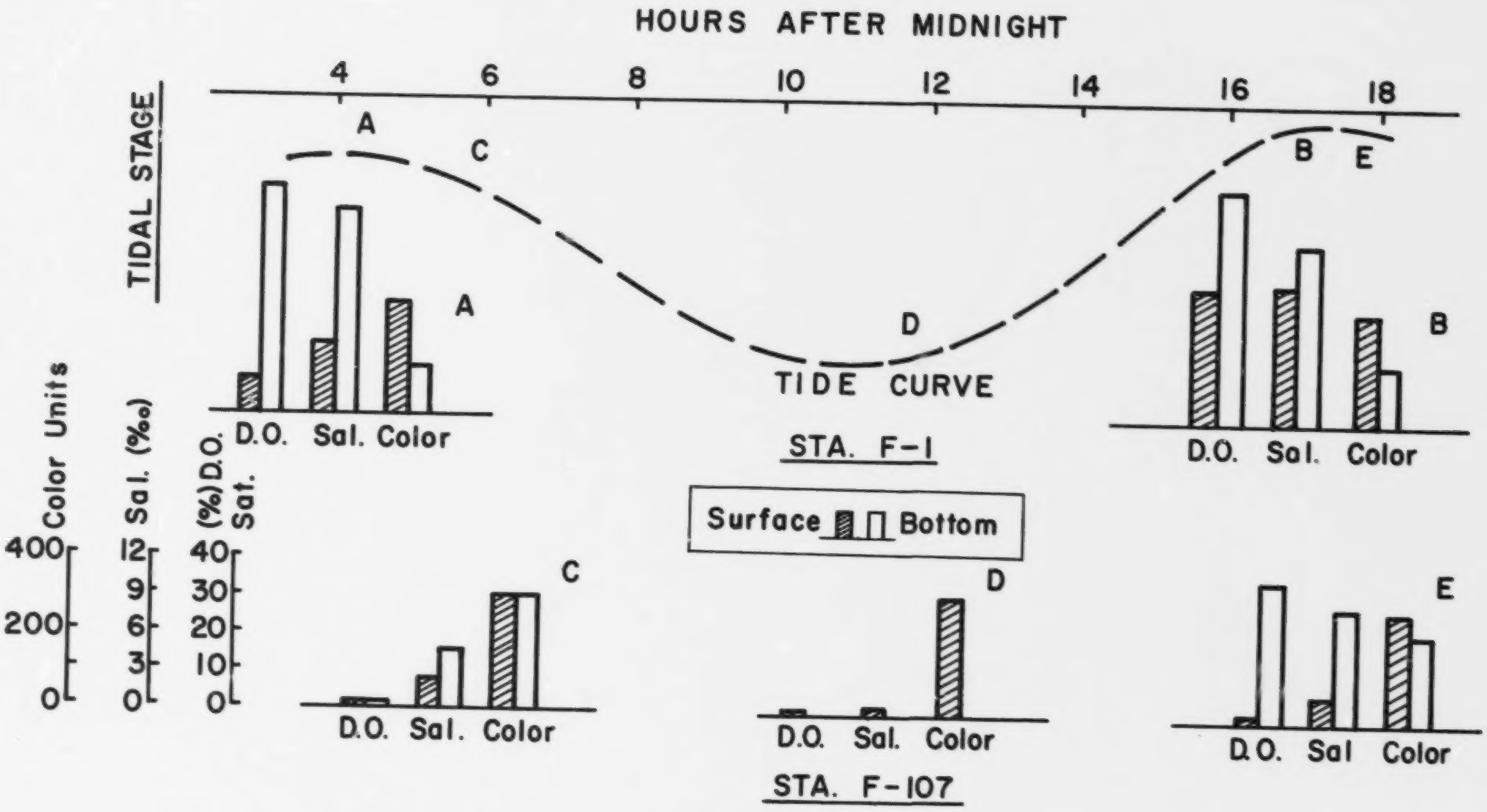


Figure FJ-6
Concentrations of Dissolved Oxygen (DO), Salinity (Sal.) and Color at Surface and Bottom Depths for Different Stages of the Tide at Stations F-1 and F-107, February 4, 1965.

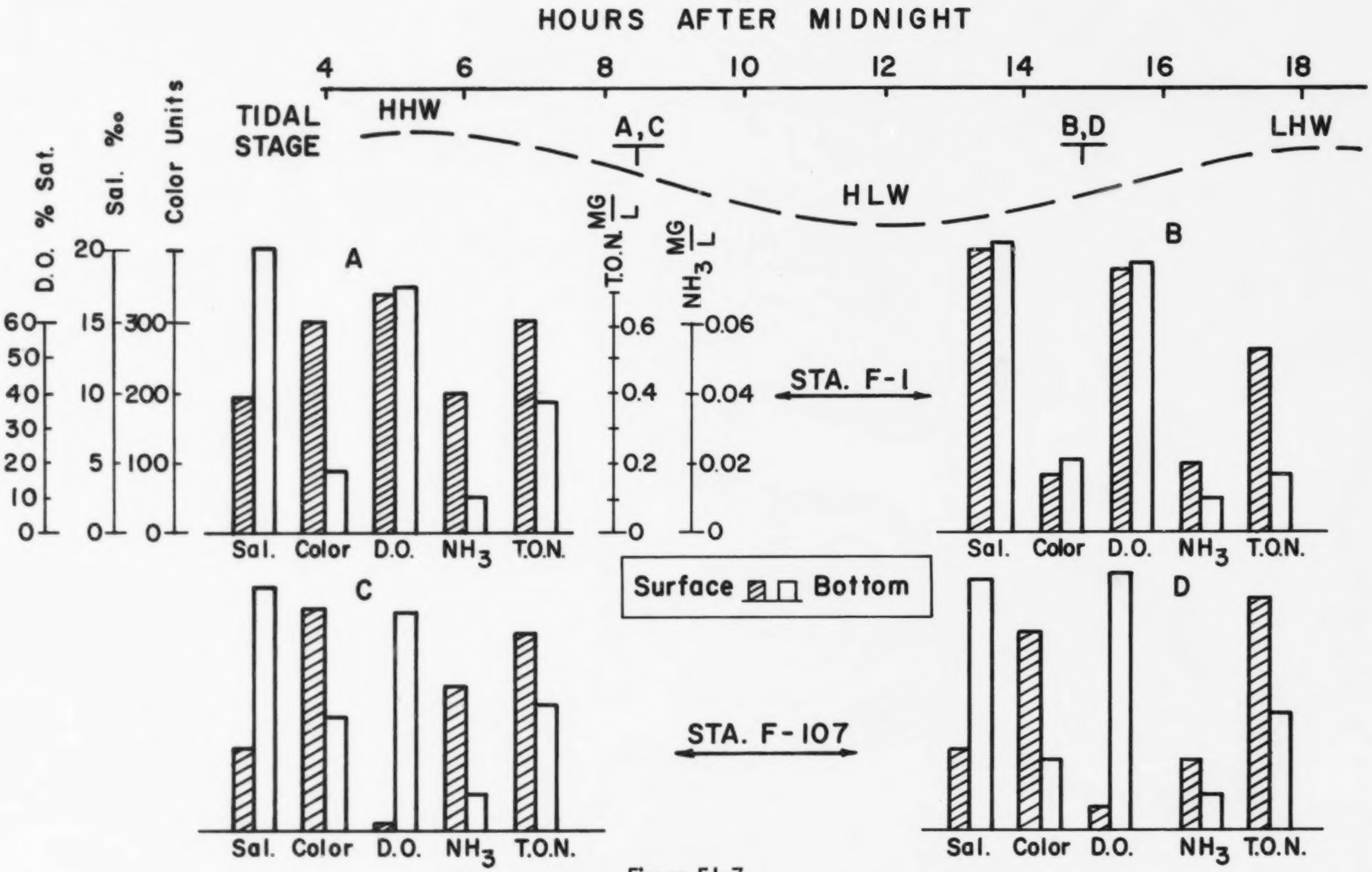


Figure FJ-7
Effect of Incomplete Vertical Mixing On Salinity (Sal.), Color, Dissolved Oxygen (DO), Ammonia (NH3), and Total Organic Nitrogen (TON), at Stations F-1 and F-107, January 22, 1965.

The chemical characteristics of the waters in these streams appear to be similar to those of the neighboring tidal waters of the Fenholloway, with the exception that dissolved oxygen is often present in appreciable concentrations in surface samples, indicating a measurable but small contribution of unpolluted fresh water to the flow in the upper reaches of Henderson River. The characteristics of these tidal streams may be summarized as follows: the upstream location, F-110, tends to have fresh water characteristics; the station near the Fenholloway, F-108, is more nearly like the main estuary in its characteristics; and Station F-109 at times exhibits both pronounced estuarine and fresher water behavior. Station F-111 has been observed on all occasions to be well mixed, only weakly saline, and strongly polluted by flow from the Fenholloway.

Chemical and Physical Properties of Adjacent Gulf Waters

The heavily polluted waters of the Fenholloway Estuary enter the adjacent shallow Gulf waters beyond Station F-1 and are dispersed over the nearshore Gulf area by the tidal currents, the action of the winds, and by turbulent diffusion. The general effects of dispersion in the Gulf are well shown in Table FI-5. The prevailing currents in this area have been described under FE. TIDAL PHENOMENA. Studies of mixing characteristics in the shallow offshore waters under relatively calm weather conditions are discussed under FK. DIFFUSION AND POLLUTION ASSIMILATION.

The sampling locations in the nearshore Gulf (Figure A-5) cover a maximum distance of approximately 9.5 miles from the mouth of the estuary. A preliminary impression of the effect of the waste dispersion upon the gross physical properties of the water can be obtained by reference to Table FJ-5, in which data on color, turbidity, and transparency at different sampling stations are presented. The sampling dates represent a wide range of fresh water flow and tidal conditions. The Gulf sampling stations are listed according to the order of increasing radial distance from Station F-1. The color at Station F-1 is quite variable, which is not surprising in view of the strong influence of the tidal stage on concentrations of fresh water at that tidal station (compare Figure FJ-7). There is in general a rough correspondence among the trends of values for color, turbidity, and transparency.

Stations F-10, F-9, and F-8 lie generally west of the mouth of the estuary, while Stations F-2, F-3, F-4, F-5, and F-6 lie in an easterly direction. Casual inspection of the concentration data in Table FJ-5 does not reveal any consistently strong tendency for strong dispersion in either of these directions. On some sampling dates one finds higher concentrations of color at Station F-2 and on others at Station F-10. A general decrease of color (and increase of transparency) with radial distance is evident in most cases. There are instances of "patchiness" but these may only reflect the superposition of transients, wind, sampling statistics, etc., on the general dispersion pattern.

At times the waters of the more distant sampling stations in the Gulf are observed to be slightly stratified, while the shallower nearshore waters have been found to be completely mixed on all occasions. These offshore waters have an appreciable fraction of fresh water reaching more than fifty per cent at times as indicated on Figure J-10.

Dispersion of Organic Pollution

The observed distributions of surface 5-day BOD values at the Gulf stations are plotted in Figure FJ-8. The general radial dispersion pattern is qualitatively similar to that already noted for color (Table FJ-5). COD concentrations show a generally similar pattern and drop off to substantially constant levels as the fresh water flow is mixed throughout the nearshore waters of the Gulf. Of course biochemical oxidation of organic substances, in addition to advection and mixing, plays a part in the observed changes in pollutant concentrations, particularly those between the mouth of the estuary and Stations F-2 and F-10. Average values for BOD and COD as well as for DO are given in Table FI-5.

Distribution of Nitrogen and Phosphorus in the Nearshore Gulf Area

Figure FJ-9 is a plot of all available data on total organic nitrogen concentrations at surface depths in the Gulf area. The total organic nitrogen includes ammonia, soluble organic substances of nitrogenous nature (e.g., amino acids) in addition to bacterial and algae cell nitrogen. Ammonia concentrations have been found to be rather small. It would be of interest to know an estimate of the soluble organic nitrogen involved in TON values. One might expect it to be on the order of micromolar concentrations. On this assumption one could consider that the large variations in TON evident in Figure FJ-9 are attributable chiefly to inherent variations in the phytoplankton and bacterial concentrations (in addition to the physical factors affecting spatial distributions).

Figure FJ-10 is a plot of surface total phosphorus (expressed as PO_4) concentrations at the Gulf stations obtained during the period January-March, 1965. As is the case for the total nitrogen, the fresh water origin of the phosphorus is generally apparent. Computation of the ratio of total atoms of nitrogen and phosphorus from the preceding sets of data (Figures FJ-9 and FJ-10) yields ratios ranging from approximately unity to seventy. It is interesting, however, that the largest number of results

Table FJ-5

SURFACE COLOR, TURBIDITY, AND TRANSPARENCY AT ADJACENT GULF STATIONS ON DIFFERENT SAMPLING DATES

Date	Flow to Estuary cfs	Station	Color Units	Turbidity Units	Transparency ft.
5/6/64	1300	F-1	500	4	
		F-2	100	6	
		F-10	100	8	
		F-3	50	4	
		F-11	15	4	
6/15/64	280	F-1	250	7.5	0.5
		F-2	200	7.5	1.0
		F-10	50	1.8	5.5
		F-3	75	7.2	4.0
		F-5	40	3.0	13
6/22/64	230	F-1	100	6	2
		F-2	85	3.2	3.5
		F-10	43	1	5
		F-3	45	2.2	5.5
		F-5	17	1.8	11.5
8/6/64	1175	F-1	600	3	0.5
		F-2	120	7	3.5
		F-10	140	1	3
		F-3	86	5	4
		F-5	36	4	10
8/17/64*	1125	F-1	520	6	0.7
		F-2	240	5	1.0
		F-10	140	8	4
		F-3	72	4	5
		F-5	31	3	11
8/24/64	1300	F-1	475	9	0.7
		F-2	125	10	3
		F-10	225	8	0.7
		F-3	84	8	7
		F-5	34	5	10
1/7/65	345	F-1	102	26	0.5
		F-2	24	5	3
		F-10	48	3	4
		F-6	19	3	4
		F-9	35	3	7
		F-3	24	5	3
		F-8	33	3	8.5
		F-7	18	3	10
		F-5	21	2	9
		F-4	20	2	2
		F-11	12	2	14
2/8/65	395	F-1	550	8	0.5
		F-2	35	2	4
		F-10	50	2	5
		F-6	40	1	4
		F-3	40	1	3.5
		F-8	35	2	7
3/1/65	400	F-1	175	32	0.7
		F-2	75	18	0.9
		F-10	100	12	1
		F-6	25	16	1.5
		F-3	60	16	1.2
		F-8	50	10	0.5
3/10/65	535	F-1	400	6	0.75
		F-2	110	5	3
		F-10	100	22	5
		F-6	60	6	5
		F-3	70	7	4
		F-8	60	2	6

*During period of Kraft Mill shutdown, 8/10/64 through 8/19/64.

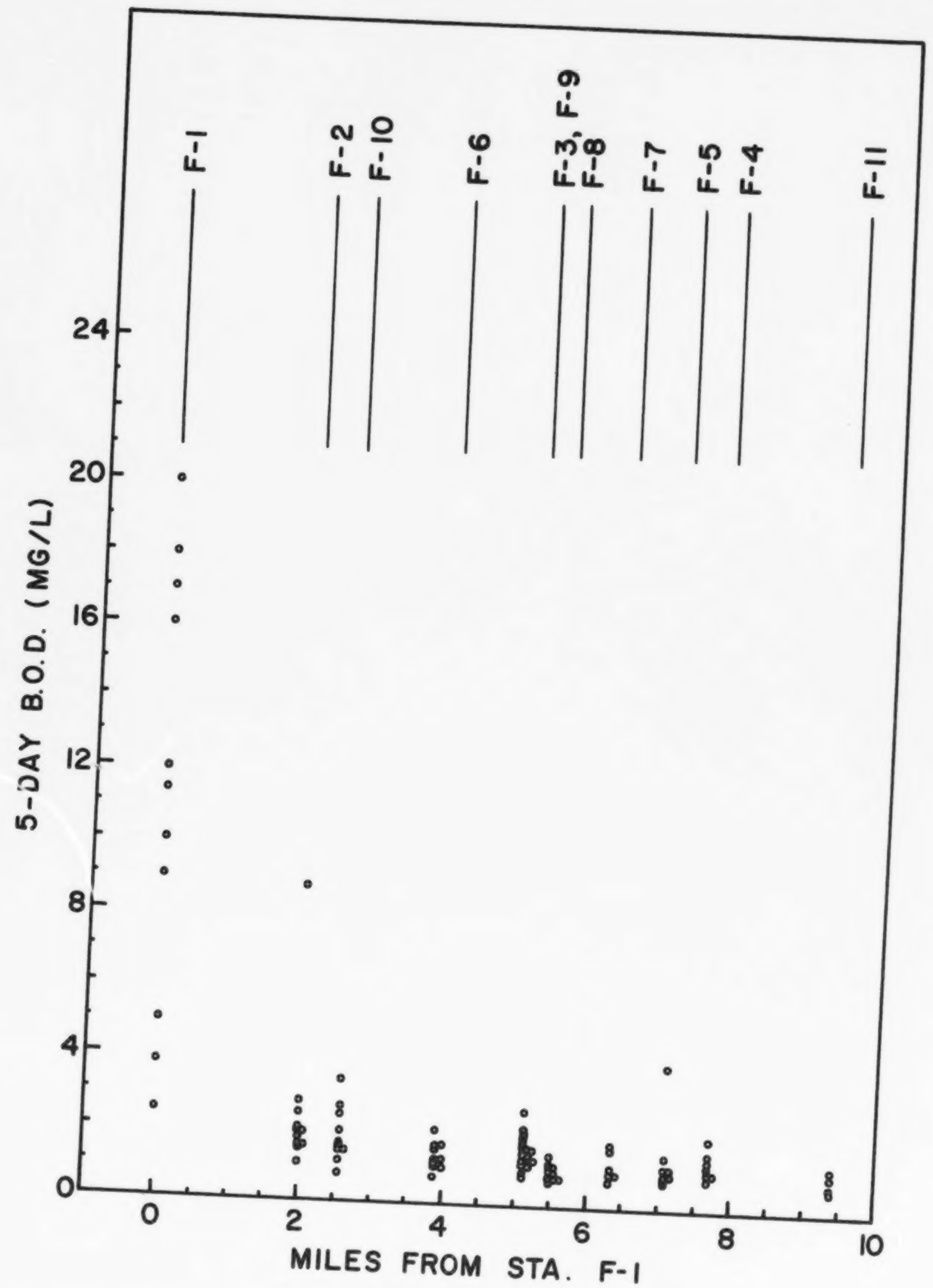


Figure FJ-8

Five-day Biochemical Oxygen Demand (BOD) Concentrations at Surface Sampling Locations in the Gulf. The Station Locations are the Radial Distances Seaward from Station F-1.

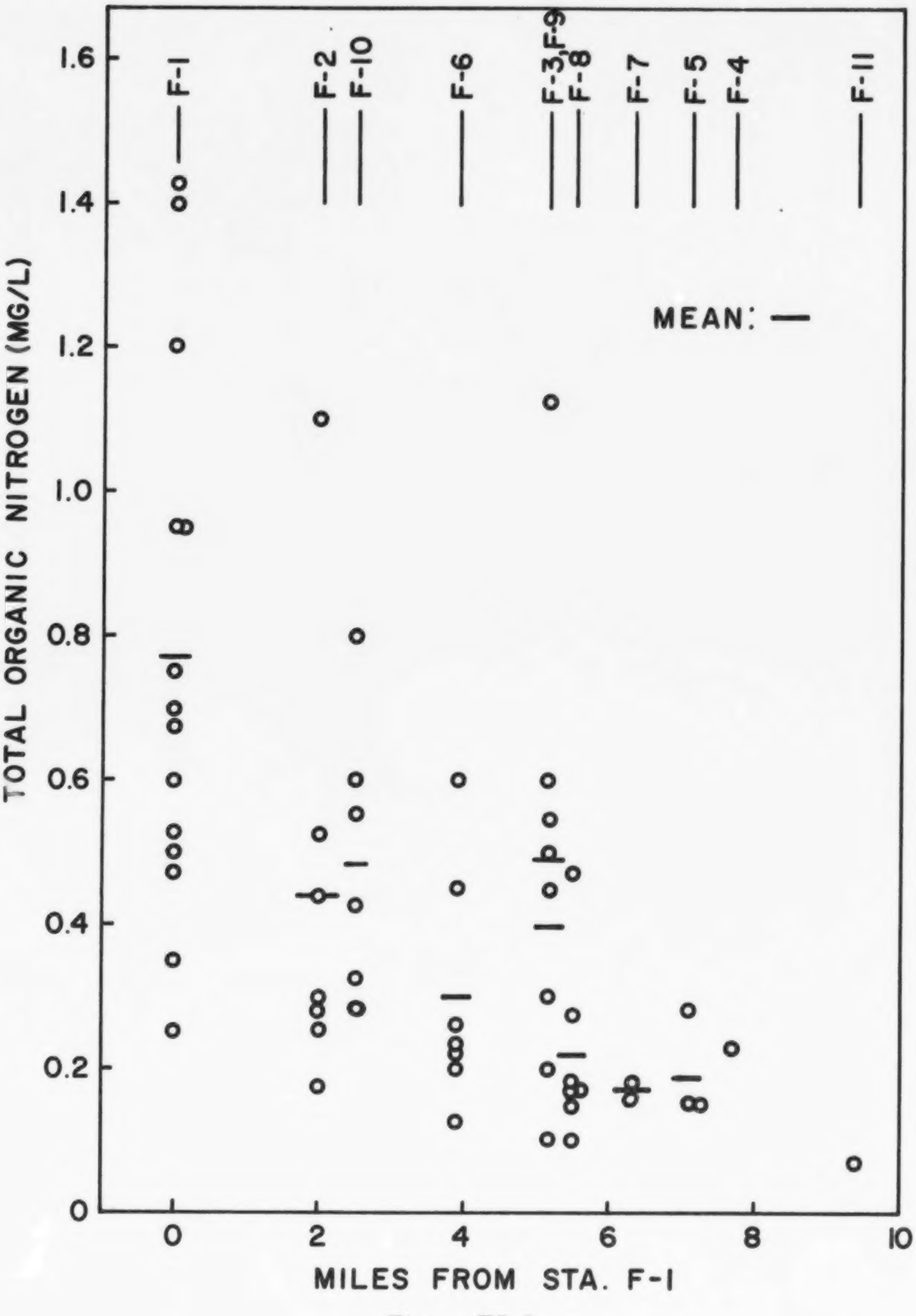


Figure FJ-9

Concentrations of Total Organic Nitrogen (TON) at Surface Sampling Locations in the Gulf.

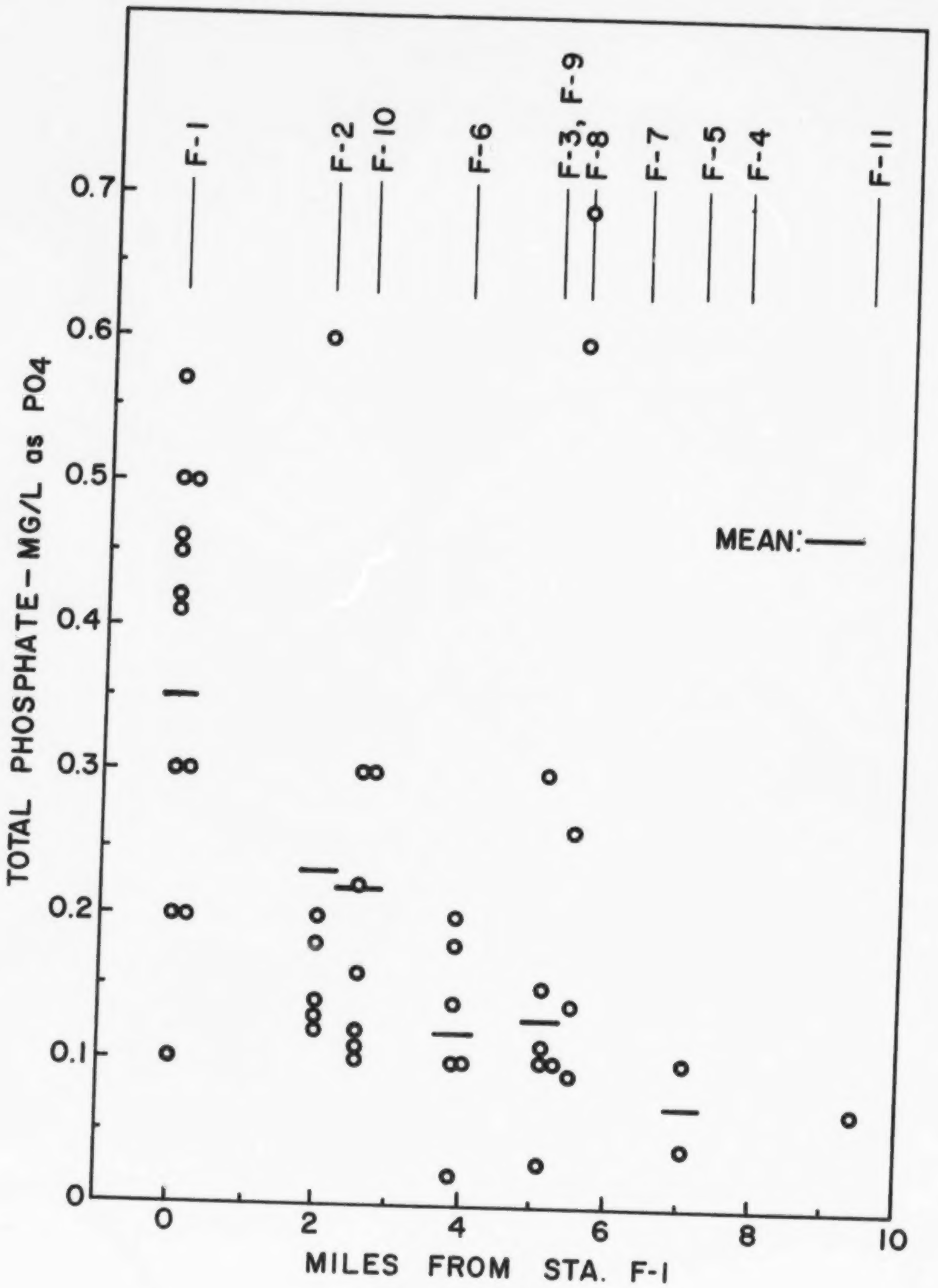


Figure FJ-10

Concentrations of Total Phosphate (as PO4) at Surface Sampling Locations in the Gulf. The Station Locations are the Radial Distances from Station F-1. The Open Circle Plotted in the Lower Right Corner Represents a Single Determination of Total Phosphate at Station F-11.

Table FJ-6

AVERAGE VALUES OF TOTAL PO_4 AT FENHOLLOWAY RIVER AND ESTUARY STATIONS

January-March, 1965

	Average Total PO_4 - mg/1 (Surface)		
Station	Low Water	High Water	Weighted Average
F-101			0.23
F-1011			1.34
F-104			0.74
F-106	0.55	0.10	0.40
F-1061	0.55	0.25	0.40
F-107	0.54	0.35	0.42
F-108		0.36	0.36
F-109		0.23	0.23
F-110		0.31	0.31
F-111		0.43	0.43
F-1	0.45	0.20	0.35

fall between ratios of roughly ten and twenty-five. Numerous analyses of algae and bacteria in ocean waters and other aquatic environments have been reported (4), and a typical average composition results in an N:P ratio of 16:1. Considerable variations from this figure can be observed for organisms growing in environments deficient in given nutrients. Thus while certainly not conclusive, the ratios of total nitrogen and phosphorus present in the nearshore Gulf waters are generally consistent with the impression that the phosphorus is almost completely present in the microorganisms.

Nutrient Levels in the Fenholloway System and Gulf

Concentrations of total phosphate in the open Gulf have been found in one survey to be usually below 0.25 μg atoms of phosphorus per liter, or 0.024 mg/1, expressed as PO_4 (9). In another study of chemical properties of the Gulf of Mexico (5) total phosphates were found to vary from 0.01 to 0.2 mg/1 as PO_4 at stations on the order of 50 miles from the coastline and at the approximate latitudes of the Waccasassa and Fenholloway Estuaries. Inorganic phosphate concentrations were considerably smaller, ranging from zero to about 0.08 mg/1 as PO_4. Nitrate concentrations at these same stations ranged from zero to 0.06 mg/1 as N. Protein nitrogen ranged from zero to about 0.2 mg/1 as N. In comparing the phosphate and nitrogen concentrations observed in the Gulf sampling program adjacent to the Fenholloway with those data just summarized, it is important to recognize that the locations of the Fenholloway sampling stations are expected to reflect fresh water influences to a much greater extent than those occupied in the earlier surveys.

Average values of total phosphate at each of the fresh water and estuary sampling stations on the Fenholloway River are presented in Table FJ-6. For tidal stations the data were also averaged for low water and high water stage conditions. Average values of total phosphate for each of the adjacent Gulf stations as reported by the Sanitary Engineering Research Laboratory, University of Florida, are presented in Table FJ-7, in which stations are listed in order of distance from Station F-1. The individual data for these averages have already been shown in Figure FJ-10. Included in Table FJ-7 are total phosphate data obtained for samples analyzed at the Woods Hole Oceanographic Institute Laboratory, Woods Hole, Massachusetts, and the Water Chemistry Laboratory of the University of Florida. The value listed for the open Gulf (Alaska Cruise, 1952) is an average value for the location indicated.

It is apparent from these data taken as a whole that total phosphates decrease with radial distance from the mouth of the estuary. The only significant departure from this trend is in the averaged data for Station F-8. A reason for this is not evident.

Nitrate concentrations when determined have been found to be quite variable. Both the kraft mill and the sewage treatment plant effluent at Perry are sources of appreciable amounts of nitrate. In addition, the natural waters of the drainage area have generally higher nitrate levels than those of the Waccasassa. Observed nitrate concentrations at Fenholloway sampling stations on eight different dates are given in Table FJ-8. These dates represent eight of the thirteen for which nitrate determinations were made. Coverage of the various stations on other dates was not sufficiently complete, or nitrate concentrations found on those dates were too low for determination. Therefore the data in Table FJ-8 are not purported to be representative – merely indicative of the nitrates found in the higher ranges of concentrations.

It seems clear that reduction of nitrate occurs under the anaerobic conditions in the stream between Station F-1011 and the estuary (June 1, 15, 22, 1964). The nitrate at Station F-1011 on March 5, 1965, agrees substantially with the result of a determination (0.52 mg/1) made on the kraft mill lagoon effluent in July, 1964.

Nitrate levels in the adjacent Gulf waters are observed to vary rather widely. The variation is actually greater than shown because of the omission of a large number of extremely small undetectable results. In contrast to the case with phosphates, there are frequent occasions when nitrate concentrations in Gulf samples are of the same order of magnitude as total organic nitrogen concentrations. This suggests that inorganic phosphate levels are limiting for phytoplankton growth in the Fenholloway offshore waters.

Phosphorus and Nitrogen Fractions

Concentrations of orthophosphate were determined for both filtered and unfiltered samples collected at five of the Gulf stations on July 12, 1965. Determinations of total phosphorus and total organic nitrogen were also made on both filtered and unfiltered samples. These data are presented in Table FJ-9. The orthophosphate concentrations are in line with general expectations based upon surveys made eariler (5) (9) by others.

Table FJ-7

TOTAL PHOSPHATE CONCENTRATIONS AT ESTUARY MOUTH AND ADJACENT GULF SAMPLING STATIONS

	Total PO_4 - mg/1			
Station[*]	SERL[†] Jan.-Mar. 1965	WHOI[§] Nov. 1964	W. Chem.[‖] April 1965	Alaska[#] Cruise June, 1952
F-1, surf.	0.35	0.14	0.27	
F-1, deep	0.22		0.17	
F-2	0.23	0.15	0.07	
F-10	0.22			
F-6	0.12	0.06		
F-3	0.13	0.14		
F-8	0.42	0.24		
F-5	0.07	0.07		
F-4		0.07		
F-11		0.07		
Gulf[‡]				0.09

[*] All surface samples, except as noted for F-1.

[†] Arithmetic means of all surface samples. At F-1, the mean for *high water* samples was 0.20 mg/1, while the mean for *low water* samples was 0.45 mg/1. Sanitary Engineering Research Laboratory, University of Florida.

[‡] Approximately 30 miles west of the estuary.

[§] Woods Hole Oceanographic Institute..

[‖] Water Chemistry Laboratory, University of Florida.

[#] U. S. Fisheries and Wildlife Service, Fisheries Report No. 249, 1958. See REFERENCES (5)

Table FJ-8

NO_3-N DATA OBTAINED ON DIFFERENT SAMPLING DATES FENHOLLOWAY RIVER, ESTUARY, AND GULF FRESH WATER FLOW: 230-1400 CFS

Date	Flow to Estuary cfs	NO_3-N - mg/1								
		F-101	F-1011	F-103	F-106	F-1	F-2	F-10	F-8	F-5
3/23/64	775					0.02	0.02	0.014	0.22	0.014
4/7/64	360				0.014	0.02	0.02	0.01	0.011	0.007
5/6/64	1300				0.23	0.67	0.87	0.21	0.18	
6/1/64	265	0.14		0.46	0.30	0.56	0.48	0.18	0.27	0.29
6/15/64	280	0.18		0.58	0.07	0.07	0.15	0.09	0.17	0.23
6/22/64	230	0.30		0.65	0.07	0.05	0.09	0.15	0.05	0.12
6/29/64	300					0.10	0.28	0.30	0.24	0.26
3/5/65	885	0.08	0.53	0.05		0.07				

Table FJ-9

ORTHOPHOSPHATE, TOTAL PHOSPHORUS, AND TOTAL ORGANIC NITROGEN AT ADJACENT GULF STATIONS, JULY 12, 1965

Station	Tidal Stage	Orthophosphate mg/1 as PO_4		Total Phosphorus mg/1 as PO_4		Total Organic Nitrogen mg/1 as N	
		Filtered	Unfiltered	Filtered	Unfiltered	Filtered	Unfiltered
F-2	High	0.024	0.029	0.50	0.60	0.84	1.05
	Low	0.024	0.053	1.44	2.23	0.71	1.47
F-6	High	0.014	0.046	0.32	0.52	0.53	0.58
	Low	0.009	0.031	0.36	1.35	0.52	0.90
F-3	High	0.010	0.023	0.44	0.72	0.85	0.89
	Low	0.028	0.032	0.40	1.05	0.58	0.87
F-8	High	0.002	0.034	0.28	0.36	0.59	0.58
	Low	0.026	0.038	0.52	0.82	0.46	0.82
F-4	High	0.015	0.045	0.76	0.86	0.62	0.54
	Low	0.023	0.033	0.40	0.79	0.56	0.71

In examining the data for total organic nitrogen, one notices that, as in the case of orthophosphates, the filterable fraction is rather variable in the different samples. The fraction of TON filterable ranges from 80 to 100 per cent for high tide samples and from 50 to 80 per cent for those collected during low tidal stage. Concentrations of nitrate in all samples were low, i.e., less than 0.05 mg/l N.

The approximate ratio of total nitrogen atoms to total phosphorus atoms was computed for the sample data in Table FJ-9. The computed atomic ratios ranged from four to twelve. For the nitrogen and phosphorus retained on the membrane filter, the computed atomic ratios ranged from approximately two to fourteen, while those for filtrate nitrogen and phosphorus varied from four to fourteen. Note that under the previous caption of *Distribution of Nitrogen and Phosphorus in the Nearshore Gulf Area* all earlier data on total nitrogen and total phosphorus summarized in Figures FJ-9 and FJ-10 respectively indicated atomic N:P ratios from unity to seventy. However, thirty-one of the thirty-five observations yielded N:P ratios lying between five and twenty-five and an arithmetic mean ratio of thirteen. In contrast, in the Waccasassa Bay waters the N:P ratio is consistently on the order of from 6:1 to 12:1, indicating a relative nitrogen deficiency. The results of the July 12, 1965, determinations of nitrogen and phosphorus in the Gulf waters adjacent to the Fenholloway are thus in general accord with the January through March observations.

Productivity Potential

It is of some interest to compare the total N:P ratios just described with estimates of the relative nitrogen and phosphorus concentrations observed in the upper fresh water sections of the Fenholloway, namely, unpolluted fresh waters; the Fenholloway below the draft effluent discharge; and on Spring Creek, above its confluence with the main stream. The few data available on total organic nitrogen, nitrate, and total phosphorus at Station F-101, above the pollution, allow a rough estimate of the total N:P ratio of twenty-five to be made. At Station F-1011, below the mill waste discharge point, the estimated N:P ratio is fourteen, based on several observations of TON, NO_3, and Total P at that point. At Station F-103 the influences of the treated sewage effluent from the town of Perry upon stream quality are in evidence, one of these being relatively high phosphorus concentrations. A N:P ratio of seven has been estimated from the limited (but rather consistent) data available. At Station F-104 on the Fenholloway above its confluence with Spring Creek, results for a single sample yielded an approximate N:P ratio of seventeen, in qualitative agreement with the joint influence of fresh water and waste effluent upon stream characteristics. The relative magnitude of the total N:P ratios indicate that both the kraft mill waste and the domestic waste from the town of perry are major sources of phosphorus. The extent to which this fact affects the availability of nutrients for plant growth in the Fenholloway Estuary and nearshore Gulf waters depends, of course, upon the forms of the phosphorus and nitrogen present in the waters. During the time of flow from the sources of pollution to the mouth of the estuary, a variety of microbiological processes might alter not only the chemical forms but also the total amounts of these elements. Among these processes are denitrification and nitrogen fixation. In the case of phosphorus, in analogy with recent interpretations advanced for microbiological involvement in transformations of the element in lakes (10), one can expect that complex biological processes are involved in its distribution between estuarine and Gulf waters, the microflora, and the sediments. It seems clear in any case that the *potential* for ultimate enhancement of of aquatic plant growth is greater as a consequence of additional sources of both nutrients, nitrogen and phosphorus.

Summary

The data presented and discussed in this section show rather clearly that kraft mill pollution exerts a strong influence upon the chemical properties of the Fenholloway River and Estuary. The influence is less striking the adjacent Gulf waters, but there too the presence of residual pollution is evidenced, particularly at points within approximately three miles from the mouth of the estuary. Within this range, dissolved oxygen levels generally increase toward the open Gulf, and such parameters as color, lignin, BOD, COD, and total phosphorus decrease, indicating the dispersion of the polluted fresh water in the saline waters of the Gulf of Mexico. Beyond three to five miles from the mouth of the estuary, little evidence exists of pollution from the Fenholloway.

The organic constituents of the kraft mill waste discharged above Station F-1011 on the Fenholloway are degraded biologically to an appreciable extent in traveling the more than twenty-five miles to the mouth of the estuary at Station F-1. This is reflected in the completely anaerobic conditions existing at nearly all times from Stations F-1011 to F-107 and in the decrease in the concentrations of BOD, COD, volatile solids, and lignin over that ascribable to simple dilution between these same stations. In addition to affecting the levels of organic matter in the stream, the kraft effluent significantly increases the amounts of sulfate, chloride, phosphate, and nitrates in the Fenholloway fresh water.

As in the Waccasassa studies, the influence of tidal mixing and circulation upon temporal and spatial variations in chemical parameters is evident at the estuarine stations in the Fenholloway. Incomplete vertical mixing exists at all points in the estuary during certain portions of the tidal cycle and is most pronounced at high water. The longitudinal mixing of saline waters of the Gulf with the polluted and oxygen-free fresh waters entering the estuary from upstream results generally in a steep dissolved oxygen profile between Station F-107 and the Gulf stations nearest to the mouth of the estuary. Similar profiles are noted for sulfate, salinity, color, phosphorus, and nitrogen.

In comparing the overall chemical characteristics of the Fenholloway and Waccasassa systems, it is obvious that the major differences arise from the presence of a significant point source of industrial pollution upstream on the former. The initial differences in color, alkalinity, and possibly nitrogen for unpolluted fresh waters of the two rivers are of little or no significance in comparison to the differences caused by introduction of the industrial effluent into the Fenholloway. The treated domestic waste flow entering the Fenholloway from Spring Creek is an additional factor leading to the observed chemical differences for the two systems. These differences manifest themselves in comparing the behavior of the Waccasassa from Stations 1 to 10 with that of the Fenholloway from Stations F-1011 to F-3 or F-8 inclusive. The Waccasassa is characterized as aerobic throughout, relatively low in organic material, and somewhat deficient in nitrate nitrogen with respect to available phosphorus. The Fenholloway is anaerobic to Station F-107, contains an apparently large number of carbonaceous and nitrogenous compounds which are degraded both aerobically and anaerobically, and contains initially appreciable nitrate which is reduced under the anaerobic conditions prevailing. Physically the Fenholloway is highly colored and turbid over most of its length below Station F-1011, containing large amounts of volatile suspended materials. The Waccasassa, on the other hand, contains relatively less color and turbidity under comparable hydrologic conditions. Beyond the radial distances from the mouth of the Fenholloway corresponding roughly to that at Station F-3, the observed chemical differences between Fenholloway and Waccasassa waters are not pronounced.

FK. DIFFUSION AND POLLUTION ASSIMILATION

Introduction

The determination of eddy diffusivity coefficients in the Fenholloway Estuary was attempted using dye and salinity measurements as in the Waccasassa Estuary. There were a number of factors which caused the tracing of dye in the Fenholloway Estuary (Figure A-5) to be impracticable. The high color and turbidity encountered under practically all flow conditions caused interference with fluorometer readings so that accurate determinations of dye concentrations could not be made with the variation in range of color and turbidity that existed along the estuary during a tidal cycle.

An additional complication was the combination of steepness and short length of the estuary as discussed under FE. TIDAL PHENOMENA. The length of the Fenholloway River subject to tidal action is about four miles, and the mean tide level slope is more than twice that of the Waccasassa. This causes a high rate of flushing in the main estuary, even at the lowest rates of flow observed during the period of the study. The result of the high degree of flushing in that dye placed in the river near the head of tidal action (Figure A-5) was carried out well beyond the mouth on the ebb tide. Little of this dye was returned to the estuary on the following flood, and it was not feasible to define the rate at which the dye diffused within the estuary as lateral and vertical homogeneity were not approached during any ebb flow.

Coefficient of Diffusivity by Internal Tracer*

It was found that the Fenholloway has an approximate exponential relation between length and cross-sectional area, as does the Waccasassa. A plot of distance against cross-sectional area is shown in Figure FK-1; the exponential coefficient is 1.05 per mile in the Fenholloway, compared with 0.55 per mile in the Waccasassa.

Salinity measurements were made in the Fenholloway by induction salinometer at several stages of fresh water flow. From these data diffusivity coefficients were computed utilizing the equation developed by O'Connor and Lawler:†

$s = s_0 e^{\frac{(Q/EA_0)(1-e^{-ax})}{a}}$, where s and s_0 are the relative salinities at any cross section and at the first upstream cross section ($x=0$), respectively. Relative salinity (a pure number) is the ratio between the salinity at any point in the estuary to the salinity at an offshore point where further increase in mean salinity becomes negligible (S_{max}).

Plotting the logarithm of relative salinity against the expression ($1-e^{-ax}$), the value of the eddy diffusivity coefficient E can be calculated, as described under K. DIFFUSION AND POLLUTION ASSIMILATION for the Waccasassa. Figure FK-2 shows such a plot for the data of October 20, 1964, when the fresh water flow was 460 cfs. The value of E determined from this plot was 2.2 square miles per day (6.6×10^5 cm^2 per second). Values

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*Coefficient of Diffusivity "E" is required in various formulae or procedures dealing with diffusion, both those used herein and those used by other investigators.

†Mathematical Analysis of Water Quality of the Waccasassa River, Florida. Donald J. O'Connor and John P. Lawler. Appendix to separate Section K.

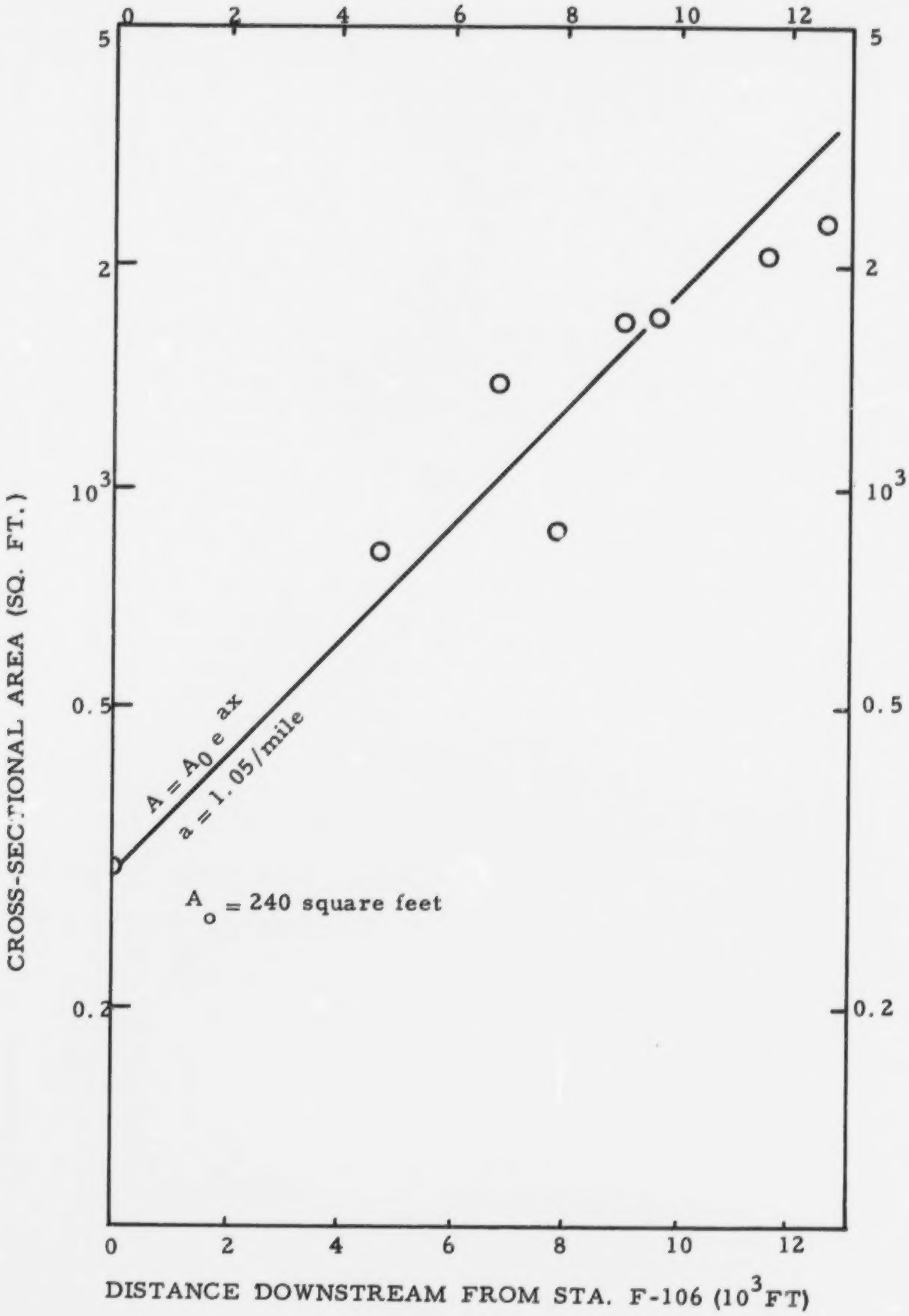


Figure FK-1

Distance Vs. Cross-Sectional Area,
Fenholloway Estuary

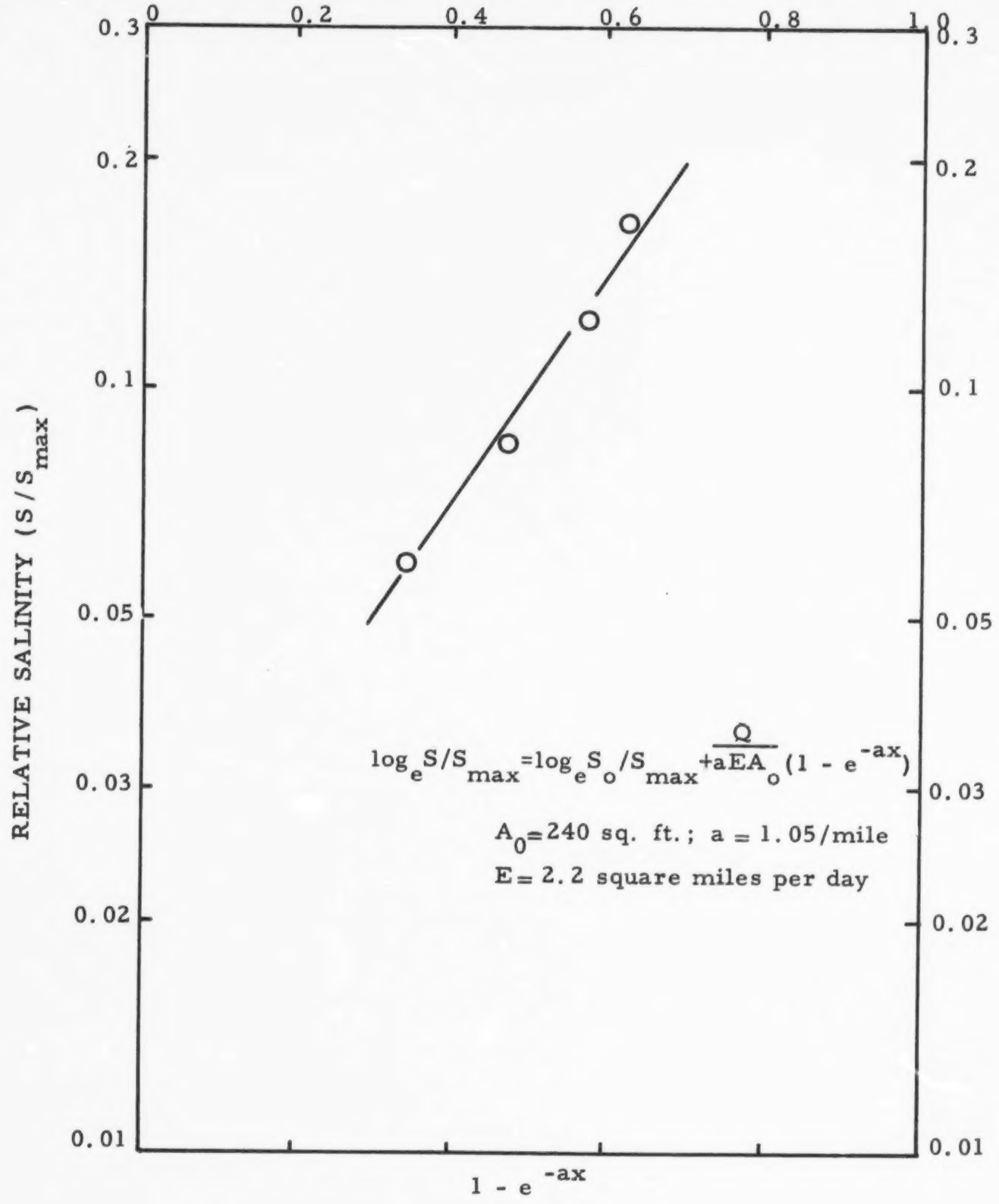


Figure FK-2

Plot of Relative Salinity Vs. $(1 - e^{-ax})$
For Calculation of Eddy Diffusivity Coefficient
Fenholloway Estuary, October 20, 1964

for E in the Fenholloway Estuary for flows between 250 and 500 cfs obtained from salinity intrusion data ranged from 1.5 to 2.3 square miles per day (4.5×10^5 to 6.9×10^5 cm^2 per second). It should be pointed out, however, that the use of the above equation involving the longitudinal salinity gradient to estimate diffusivity is based on the assumptions that salinity intrusion in the estuary is due primarily to diffusion processes rather than to density flow, and that E is constant in the section of the estuary under consideration. The Fenholloway can be be classified as partially mixed, but it is more stratified than the Waccasassa with regard to salinity intrusion as discussed under FE. TIDAL PHENOMENA. The use of the above relationship to estimate the eddy diffusivity coefficient should be considered as an approximation which appears to be of the same order of magnitude as that found in the Waccasassa. Bowden (10) maintains that the use of longitudinal salinity distribution need not be restricted to estuaries which are vertically homogeneous, provided mean values are used at each station.

For the reasons given previously, use of a dye as a tracer within the estuary was not feasible. The following discussion therefore deals with pollution assimilation phenomena in the nearshore waters of the Gulf where most of the estuary pollution is dispersed. In effect this region may be considered as simulating an embayment at the entrance to the estuary.

Coefficient of Diffusivity in Nearshore Gulf Areas by External Tracer

The mixing characteristics of the shallow nearshore areas of the Gulf outside the estuary are of importance in predicting the rate of dispersion of identifiable components of the pollution in these waters. Several instantaneous dye dumps were made at locations one to two miles offshore from the mouth of the Fenholloway, and the spread of the dye was followed for three to four hours by means of the Turner fluorometer with continuous flow door, operated aboard a boat 17 feet long, 5.5 feet beam, and drawing about 12 inches loaded. It was necessary to operate during periods when wind and wave action were not severe. On two occasions wind and wave action increased so rapidly as to cause cessation of operations before satisfactory results could be obtained. The movements of the dye cloud with the current made it necessary to be able to determine its major and minor axes visually, in order to maneuver the boat so as to measure the length of the axes and the variation of dye concentration along them. When the wave chop exceeded approximately 1¼ feet, the dye cloud quickly became very difficult to define, and the measurement of distances and operation of the instrument with its accessory equipment (such as the AC generator and pump) became almost impossible due to severe rolling and pitching of the boat.

Theoretically a larger boat of great draft would have enabled operations to be conducted under more nearly average conditions. However, the shallow depths (1.5 to 3.0 feet MLW) over much of the nearshore area (Plate III) required a shallow draft boat. As the mean tidal range is about 2.5 feet, careful placement of the dye was necessary in order to prevent the boat from running aground.

In view of the results of previous investigations in open waters, it was believed that differences would be found between diffusion rates in the direction of the tidal current and in a direction normal to the current. Appreciable differences in coefficients parallel to and normal to the principal currents were found by Wright (11) in studying diffusion in the Irish Sea.

It appeared to be a reasonable assumption that the diffusion could be considered essentially two-dimensional as the variation in depth in the area under study is only about two to four feet, with maximum depths of about six feet. Preliminary dye tests confirmed that the dye cloud tended to remain stratified within a layer approximately three feet thick for four hours or more, with the maximum concentration at the depth of release which was 1.5 feet below the surface.

Theoretical Considerations. The two-dimensional solution utilized in the Irish Sea (11) work assumes that diffusion from a point source in an open body of water forms an elliptical pattern with the major axis in the direction of the principal current. Diachishin (12) has reported on several methods of diffusion analysis used by Wright and others.

The two-dimensional solution of the diffusion equation in terms of concentration is:

$$C = \frac{Kxy}{t}\, e^{-\frac{t}{4}\left[\frac{(x-\bar{u}t)^2}{E_x} + \frac{(y-\bar{v}t)^2}{E_y}\right]}$$

The constant K_{xy} has the following relationship to E_x and E_y, and to the weight of the dye mass, W:

$$K_{xy} = \frac{W}{4\pi\,(E_x E_y)1/2}$$

Using the normal form by making the substitutions:

$$\sigma_x = (2E_x t)^{1/2} \quad \text{and} \quad \sigma_y = (2E_y t)^{1/2}$$

the solution becomes

$$C = \frac{W}{2\pi\sigma x\sigma y}\, e^{-\frac{1}{2}\left[\left(\frac{x'}{\sigma x}\right)^2 + \left(\frac{y'}{\sigma y}\right)^2\right]}$$

where $x' = x - \bar{u}t$ and $y' = y - \bar{v}t$

The maximum concentration is found at the point of symmetry and is given by

$$C_{max} = \frac{W}{2\pi\sigma x\sigma y}$$

If logarithms are taken of both sides in the solution above, we obtain

$$\text{Log}_e\left(\frac{C_{max}}{c}\right)^2 = \left(\frac{x'}{\sigma_x}\right)^2 + \left(\frac{y'}{\sigma_y}\right)^2$$

Iso-concentration lines within the dye cloud form ellipses, whose areas are given by πab, where a and b are the semi-axes, major and minor. The relationship between the variances (σ_x^2 & σ_y^2) and the semi-axes are:

$$a^2 = \sigma_x^2 \log \left(\frac{C_{max}}{C}\right)^2 \qquad b^2 = \sigma_y^2 \log \left(\frac{C_{max}}{C}\right)^2$$

and the areas of each of the ellipses in terms of concentration and variance will be:

$$A = \pi \sigma_x \sigma_y \log \left(\frac{C_{max}}{C}\right)^2$$

Areas within the iso-concentration lines are determined by measurement of concentration using several longitudinal and lateral traverses of the elliptical cloud. The areas thus found are plotted against the logarithms of the iso-concentration lines of the dye, and a straight line is fitted to the points for each increment of elapsed time from the time of release. The plot thus indicates the elliptical area enclosed by each iso-concentration line which contains that concentration and all higher concentrations of dye. Thus in Figure FK-3 the area for $t = 0.7$ hours for the iso-concentration line of 10^{-2} mg/l is 17.5×10^3 square feet. Using the ratio of maximum concentration for this time increment to 10^{-2} mg/l (the iso-concentration line selected), one obtains:

$$\sigma_x \sigma_y = \frac{\pi A}{\log_e (C_{max}/c)^2}$$

σ_x and σ_y are related to the semi-axes of the ellipses thus:

$$\frac{\sigma_x}{\sigma_y} = \frac{a}{b}$$

Since a and b are known for each ellipse, their ratios are used to solve for σ_x and σ_y. Then one can obtain the two horizontal eddy diffusivity coefficients from the relationships:

$$E_x = \frac{\sigma_x^2}{2t} \qquad E_y = \frac{\sigma_y^2}{2t}$$

Dye Releases. Dye releases were made on August 31 and November 12, 1964. The earlier release was made just east of Rock Island (Plate III) about three miles WSW of the mouth of the estuary. The release in November was at a point one mile due south of the estuary mouth. It was possible to follow the dye visually, making area and concentration measurements for three to four hours before the clouds became too ill-defined to determine the location of the axes. The shapes of the dye clouds were not perfectly elliptical as there was a slight cross wind in each instance, which caused the leading edge to curve away slightly from the normal track of the current, as shown in Figure FK-4. The photograph shows the Rhodamine B dye cloud on the left and a cloud of Fluorescein on the right. The Fluorescein was released only to compare the shape and persistence of the pattern with that of the Rhodamine. The shape and visual persistence of the two clouds were quite similar.

From the data obtained, values were determined for the horizontal eddy diffusivity coefficient using the relationships and formulae discussed above. The mean values found were as follows:

Date 1964	E_xSq.Ft./Sec.	E_x(cm^2/Sec.)	E_ySq.Ft./Sec.	E_y(cm^2/Sec.)
Aug. 31	1.4	1.3×10^3	0.054	50
Nov. 12	1.8	1.7×10^3	0.058	54

These values for diffusivity coefficients are valid for the existing conditions and the scale of the dye cloud during the observations. It has been summarized and reported by Pearson (13) that the value of horizontal eddy diffusivity is a function of scale of the phenomena. The reasoning advanced for the increase in value with scale is that two particles in a turbulent field will tend to separate at a rate which increases with the distance by which they are separated, since the particles become entrained in larger and larger eddies as they move away from each other. There seems to be a four-thirds power scale relationship rather than linear, based on a large number of values found by various investigators.

Figure FK-5 shows the variation of eddy diffusivity coefficients with scale according to Pearson as developed from the observations of a number of investigators. The values of E_x and E_y as found on the two occasions when measurements were taken in the Gulf offshore from the Fenholloway Estuary (Figure A-5) are plotted at the mean scales of the longitudinal and lateral axes of the clouds, respectively. Agreement with Pearson's equation $E = 0.001 L^{4/3}$ appears to be satisfactory.

Pollution Assimilation Characteristics of the Nearshore Gulf Waters

In any study of a polluted estuary emptying into a large body of water it is important to learn something about the probable distribution and concentration of the pollutant in the vicinity of the estuary mouth. At any point beyond the mouth the concentration of a nonconservative constituent of pollution will be a function of eddy diffusion and natural decay, as well as of any currents that may exist. Currents in the nearshore Gulf Waters beyond the estuary mouth are primarily tidal and wind-generated, although river outflow affects the current pattern very near the mouth. Variations are so large and the circulation pattern so complex as to make a mathematical analysis of the effect of winds, tides, and variable river flow on pollutant distribution an extremely difficult if not impossible task.

Since the flushing action of the Fenholloway is quite rapid under most flow conditions, as is discussed later, and since the pollution is emptied from the mouth largely in the surface layer bacause of the degree of stratification existing, the discharge of pollution from the mouth can be treated as reasonably constant when measurements are taken during a sufficient length of time to show statistical smoothing of variations. By taking samples four or

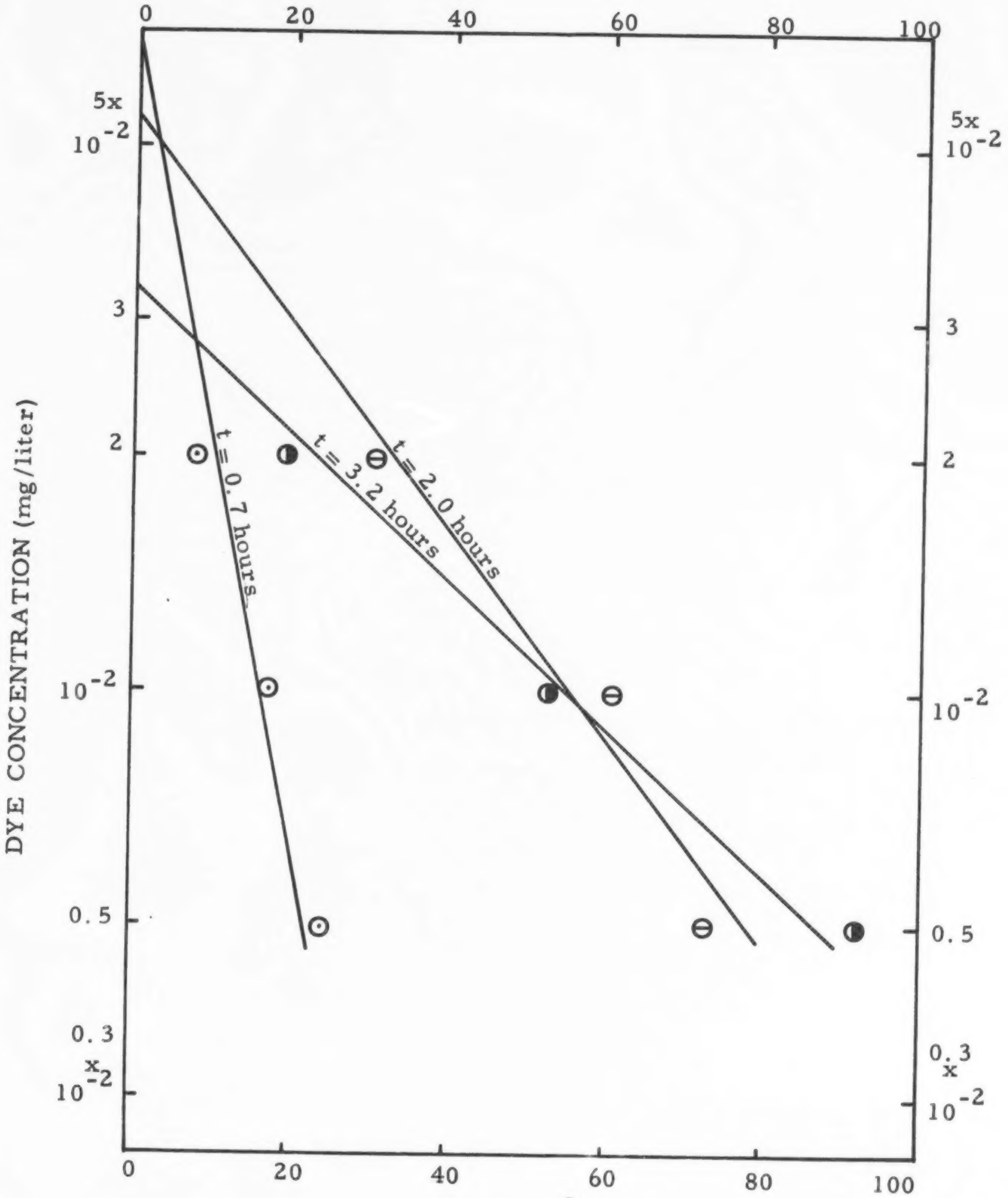


Figure FK-3

Plot of Areas of Iso-Concentration Ellipses Vs. Dye Concentration for Calculation of "E" Offshore from the Fenholloway Estuary, November 12, 1964

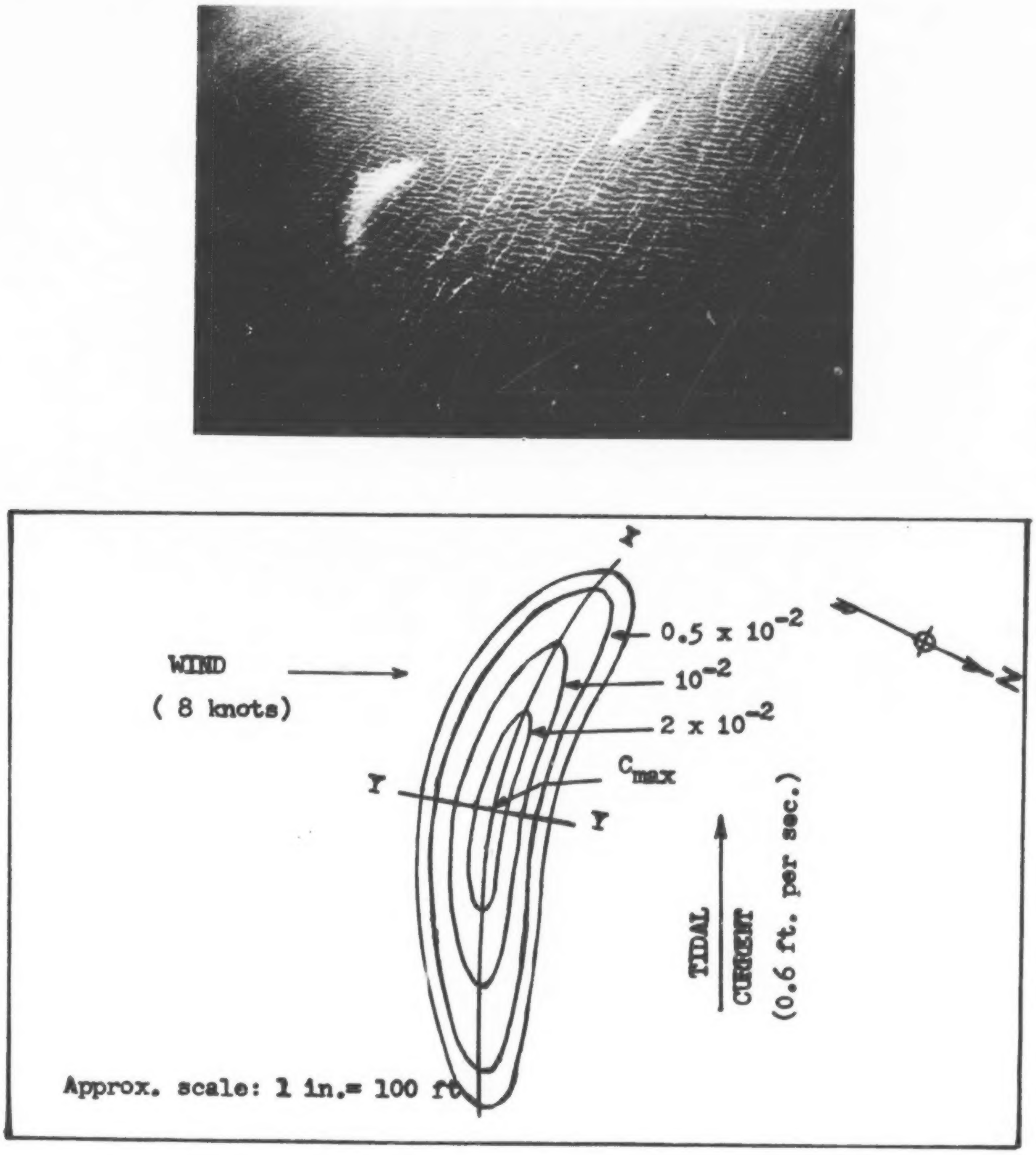
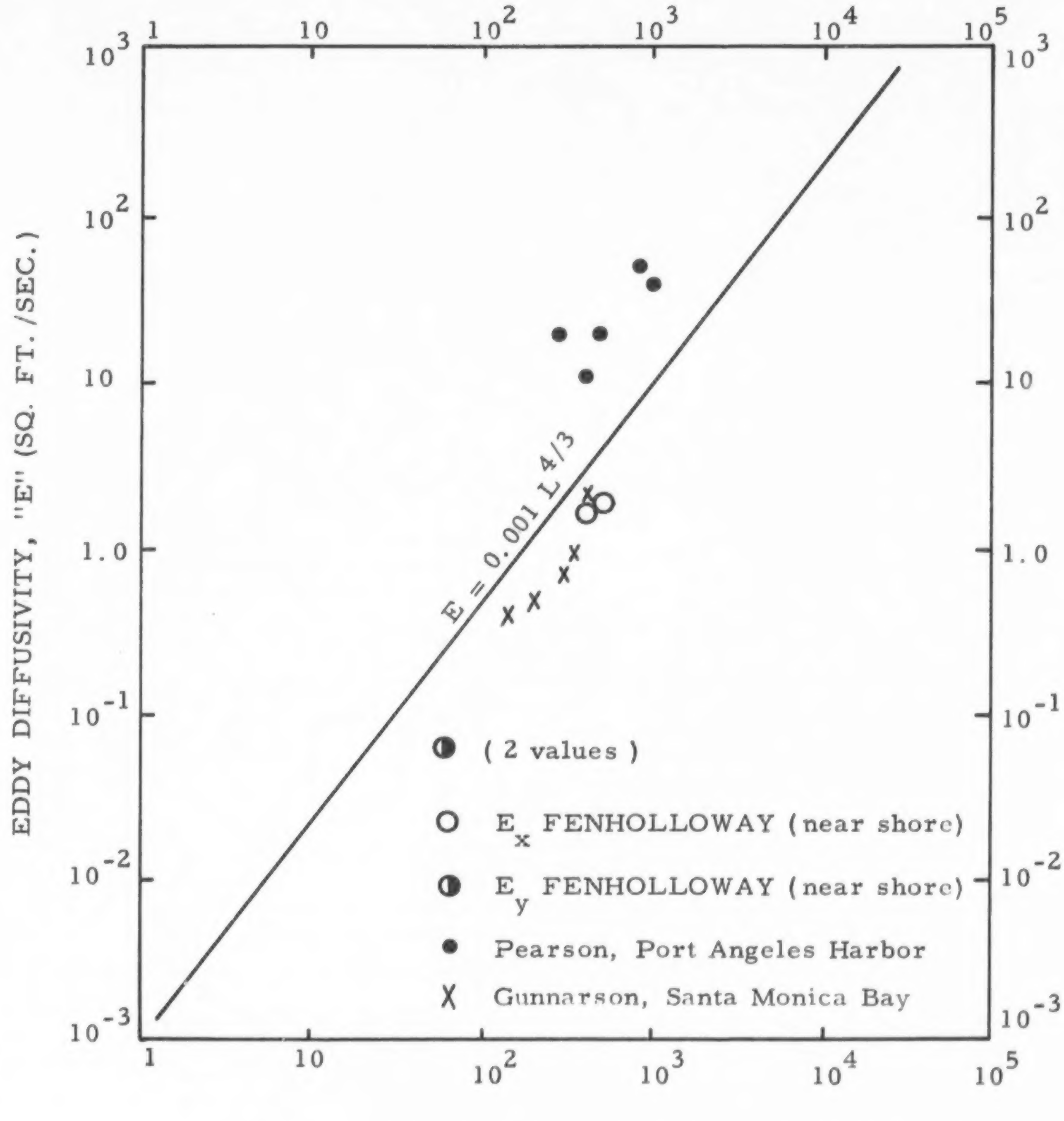

X
WIND
(8 knots)
0.5 x 10^{-2}
10^{-2}
2 x 10^{-2}
C$_{max}$
Y
Y
N
TIDAL
CURRENT
(0.6 ft. per sec.)
Approx. scale: 1 in.= 100 ft

Figure FK-4

Photograph and Diagram of Dye Cloud Showing Iso-Concentration Lines and Axes Offshore from the Fenholloway Estuary, November 12, 1964



LENGTH SCALE (FEET) After Pearson

Figure FK-5

Variation in Eddy Diffusivity Coefficients With Scale five times during a month at the mouth of the estuary and at stations in the Gulf located in several directions and at various distances from the mouth, a mean distribution of pollution for the month can be obtained for comparison with a predicted mean distribution which assumes a steady state with regard to currents, allowing eddy diffusion and decay of the pollutant to be considered the principal parameters. Such a distribution is the approximate equivalent of that in a nontidal body of water with no net preponderance of currents in one direction.

The value of the eddy diffusivity coefficient to be used in making a predicted distribution is dependent on the linear scale of the area within which the pollution is dispersed and measured, as discussed previously. In the area offshore from the mouth of the Fenholloway where Sampling Stations F-2 through F-11 are located, the length scale is on the order of 3×10^4 feet. The length scales pertinent to the dye clouds from which the horizontal diffusivity coefficients were calculated were approximately 700 feet for E_x and 90 feet for E_y. If the two coefficients are expanded to a scale of 3×10^4 feet, using the $L^{4/3}$ relationship mentioned above, E_x would be multiplied by the factor: $(\frac{3 \times 10^4}{7 \times 10^2})^{4/3}$ and E_y by the factor: $(\frac{3 \times 10^4}{9 \times 10})^{4/3}$, and the mean values at a scale of 3×10^4 feet would be:

$E_x = 210$ square feet per second (2×10^5 cm^2 per second)

$E_y = 114$ square feet per second (1×10^4 cm^2 per second)

Expressing eddy diffusivity in square miles per day, which is more useful at the scale and in the time frame involved, a mean horizontal diffusivity coefficient of 0.5 square miles per day is obtained. Although the data were taken in relatively calm weather, this value is considered to be reasonably valid for average conditions in the absence of storms. It should not be confused with values for the estuary proper inside Station F-1 determined previously by internal tracer.

Distribution of Escherichia Coli in Nearshore Gulf Waters

To supplement the determination of the coefficient of diffusivity for the nearshore Gulf waters, it was decided to investigate the pattern of pollution distribution by the use of *Escherichia coli* as the constituent to be measured. Some work on die-away rates of *E. coli* in salt water at summer, spring, and winter temperatures has been reported by Vaccaro et al. (14) on the New England coast. Temperatures in the Gulf of Mexico were naturally higher than the seasonal temperatures found in the New England study. Data were available for the Fenholloway Estuary for two summer months and one winter month as shown in Table FK-1. Average water temperatures during these months off the mouth of the Fenholloway were: June, 1964, 29°C; August, 1964, 29°C; and March, 1965, 15°C.

Values of the die-away factor "k" found by Vaccaro et al. were:

Season	Temperature	k
Summer	20°C	1.00 per day
Spring	12°C	0.85 per day
Winter	6°C	0.52 per day

Based on the above data it appears that the following values of "k" are reasonable for Gulf temperature conditions:

June-August, 1964	k = 1.2 per day
March, 1965	k = 0.9 per day

A method of predicting bacterial distribution in a nontidal body of water has been developed by O'Connor (15). Assuming constant horizontal eddy diffusivity and a first order reaction for the die-away rate of bacteria, the equation for steady state distribution of bacterial concentration is given by:

$$E \left(\frac{\partial^2 c}{\partial x^2} + \frac{\partial^2 c}{\partial y^2} \right) - KC = 0$$

If this equation is transformed to polar coordinates and the further assumption is made that concentration, "c," is constant for a given radius, "r," from the center of the estuary mouth, the partial differential equation reduces to an ordinary differential equation:

$$\frac{d^2c}{dr^2} + \frac{1}{r}\frac{dc}{dr} - \frac{kc}{E} = 0$$

This is a Bessel equation of order zero, which has for a solution:

$$c = A\, I_0 \sqrt{\frac{kr^2}{E}} + B\, k_0 \sqrt{\frac{kr^2}{E}}$$

in which I_0 and k_0 are modified Bessel functions of the first and second kinds, order zero. With boundary conditions of zero concentration at infinity and the concentration at the mouth equal to the initial concentration, with the radius equal to half the river's width at that point, the final solution is:

$$\frac{c}{c_o} = \frac{k_o \left(\frac{kr^2}{E}\right)^{1/2}}{k_o \left(\frac{kr_o^2}{E}\right)^{1/2}}$$

The radius at the mouth (r_o) of the Fenholloway Estuary is 0.14 miles and E is taken as 0.5 square miles per day as found from the previous discussion.

For the data of June and August, 1964, (Table FK-1) the die-away factor "k" is taken to be 1.2 per day. The factor $(\frac{k}{E})^{1/2}$ then becomes 1.55. By using various values of "r" in the final equation above, the ratio on the right hand side of the equation can be evaluated by referring to a table of modified Bessel functions of the second kind, order zero. Values may be found in Tables of Higher Functions by Jahnke, Emde, and Losch, NBS Applied

Table FK-1

CONCENTRATION OF E. COLI, FENHOLLOWAY NEARSHORE GULF WATERS

Station	Date	Temp. °C.	MPN/100 ml*
		June, 1964	
F-1	1	27.0	24,000
	15	28.0	1,500
	22	29.0	360
	29	30.0	11,000
F-2	1	27.0	23
	15	28.5	230
	22	29.0	9.1
	29	30.0	<3.6
F-3	1	28.0	15
	15	29.5	<3.6
	22	30.0	23
	29	30.0	<3.6
F-4	1	27.5	<3.6
	15	30.0	<3.6
	22	30.0	9.1
	29	30.0	<3.6
F-5	1	27.5	3.6
	15	31.0	<3.6
	22	30.0	<3.6
	29	30.0	<3.6
F-6	1	27.5	3.6
	15	30.0	9.1
	22	30.0	<3.6
	29	30.0	<3.6
F-7	1	27.0	<3.6
	15	31.0	<3.6
	22	30.0	<3.6
	29	30.0	<3.6
F-8	1	27.0	<3.6
	15	30.0	<3.6
	22	30.0	<3.6
	29	29.5	<3.6
F-9	1	27.0	3.6
	15	30.0	<3.6
	22	30.0	<3.6
	29	29.0	<3.6
F-10	1	27.0	7.3
	15	30.0	23
	22	31.0	3.6
	29	28.5	9.1
		August, 1964	
F-1	10	27.0	46,000
	17	27.5	2,300
	24	26.5	7,500
F-2	2	29.0	230
	17	29.0	930
	24	31.0	93
F-3	2	29.0	43
	17	29.0	9.1
	24	31.0	3.6
F-4	2	29.0	<3.6
	17	29.0	23
	24	30.5	23
F-5	2	29.0	9.1
	17	29.0	9.1
	24	30.0	<3.6
F-6	2	30.0	3.6
	17	29.0	9.1
	24	31.0	9.1
F-7	2	30.0	9.1
	17	29.0	23
	24	30.0	3.6
F-8	2	30.0	23
	10	29.0	23
	24	30.0	<3.6
F-9	10	28.5	23
	17	-	-
	24	29.5	3.6
F-10	2	30.0	75
	10	27.5	230
	17	30.0	9.1
	24	30.5	930
		March, 1965	
F-1	1	15.0	9,100
	10	15.0	1,100,000
	15	18.0	2,300,000
F-2	1	14.0	230
	10	13.0	11,000
	15	17.0	46,000
F-3	1	14.0	230
	10	13.0	4,600
	15	17.0	36
F-5	1	-	-
	10	14.0	43
	15	17.0	93
F-6	1	13.0	230
	10	13.0	2,400
	15	17.0	230
F-7	10	13.0	23
	15	17.0	230
F-9	10	13.0	23
	15	17.0	150
F-10	1	16.0	11,000
	10	13.0	23
	15	17.0	430

*MPN – Most probable number as defined in Standard Methods for the Examination of Water, Sewage, and Industrial Wastes, APHA, 12th Edition, 1965.

Mathematics, Series No. 55, and in similar publications. Finally, values of the relative concentration of *E. coli*, c/c_0, may be plotted logarithmically against the radius from the center of the estuary mouth to each of the Gulf sampling stations for which adequate data are available during the period.

The line of predicted relative concentrations of *E. coli* for June and August, 1964, is shown on Figure FK-6. It was computed as indicated in the preceding paragraph, and the mean values of the relative concentrations found at the sampling stations (identified by numbers near the top margin of the figure) during each of the months. Also shown are lines of predicted concentrations for $E = 0.25$ and $E = 1.0$ square miles per day. The same information for the conditions and sampling data of March, 1965, is shown on Figure FK-7. In the case of data shown on Figure FK-6, agreement is rather good to about five miles radius from the mouth; beyond that point relative concentrations found at the sampling stations were higher than predicted. Location of the sampling stations is shown on Figure A-5. The data for June showed generally better agreement than those for August. It should be mentioned, however, that the concentrations found during these months at the outer stations were very low and were at or near the lower limit of the method used for measurement. Agreement with the predicted concentrations was better for the data of March, 1965, shown in Figure FK-7. It is believed that to a large extent this is due to the fact that greater concentrations were found both at the mouth and at the outer sampling stations. Thus the ratio of concentrations at the sampling stations to the initial concentration at the estuary mouth was less dependent on the accuracy of the method at the lower bacterial counts.

It would appear that the agreement of measured concentrations with predictions both under summer and winter conditions tends to confirm that the ratio of "k" to "E" in each case was approximately correct. Although errors in the determination of either may well exist, it is believed reasonable to infer that they are both of the proper order of magnitude for the three months' samples taken. The conclusions from this study as to radial distribution confirm those reported under FF. MICROBIOLOGY and FJ. CHEMICAL CHARACTERISTICS.

Flushing of the Estuary

The removal of pollutants from an estuary by flow into and exchange with the receiving waters of the ocean or gulf is known as flushing. There are several actions taking place in an estuary which contribute to some extent to this process. These include the advective flow of the river or stream, tidal exchange which may be affected by wind, barometric pressure, etc., and circulation due to density currents.

In the case of the Fenholloway Estuary the advective or fresh water flow is of primary importance as this flow is substantial in proportion to the mean tide level volume and to the tidal prism, even at dry weather flows. The mean tide level volume from the mouth to the tidal limit above Station F-106 is 32×10^6 cubic feet.

The rate of renewal of water in an estuary may be expressed as "flushing time," "detention time," or "mean residence time," which are different terms for the same thing, and which refer to the average time that a particle remains in the estuary before it is exchanged with a particle which has not previously been resident in the estuary. Another parameter which may be used is the "half-life" of the estuary, which is the time necessary to replace one-half of the water resident therein. In both cases the volume of the estuary usually considered is the mean tide level volume.

New water for the renewal of water in an estuary may come both from the river flow and from tidal and wind currents from the ocean or gulf. The quantity of water for renewal from river flow can be estimated readily from stream gaging data since particles resident in the estuary do not return upstream from the tidal limit. However, some particles of water emptied into the receiving waters beyond the mouth will return to the estuary on subsequent flood tides, and the extent to which this occurs is not so easily determined.

Considering the fresh water advective flow alone, the mean residence time is given by:

$$\text{Mean residence time} = \frac{1/2 \text{ mean tide level volume}}{\text{volume of new water per unit time}}$$

where there is no mixing. If the water flowing into the estuary is completely mixed with the resident water, the rate of renewal is not linear but exponential. In the Fenholloway Estuary for a condition of no mixing and an advective flow of 300 cfs,*

$$\text{Mean residence time} = \frac{0.5\ (31.5 \times 10^6 \text{ cubic feet})}{25.9 \times 10 \quad \text{cubic feet per day}} = 0.61 \text{ day}$$

Mixing between the incoming fresh water and the resident estuarine water will increase the mean residence time. According to Pritchard (16) the mean residence time for exchange with complete mixing corresponds to the time interval required to replace a fraction of the total resident volume equal to $(1 - 1/e)$,† or 63 per cent of the resident volume instead of 50 per cent in the case of no mixing.

The half-life of an estuary, considering net advective flow only, is the same as the mean residence time for the case of no mixing. For complete mixing the half life is given by:

$$t_{1/2} = \frac{0.693}{\gamma}$$

---

*Average flow is about 440 cfs.

†"e" = base of natural logarithms (2.7183)

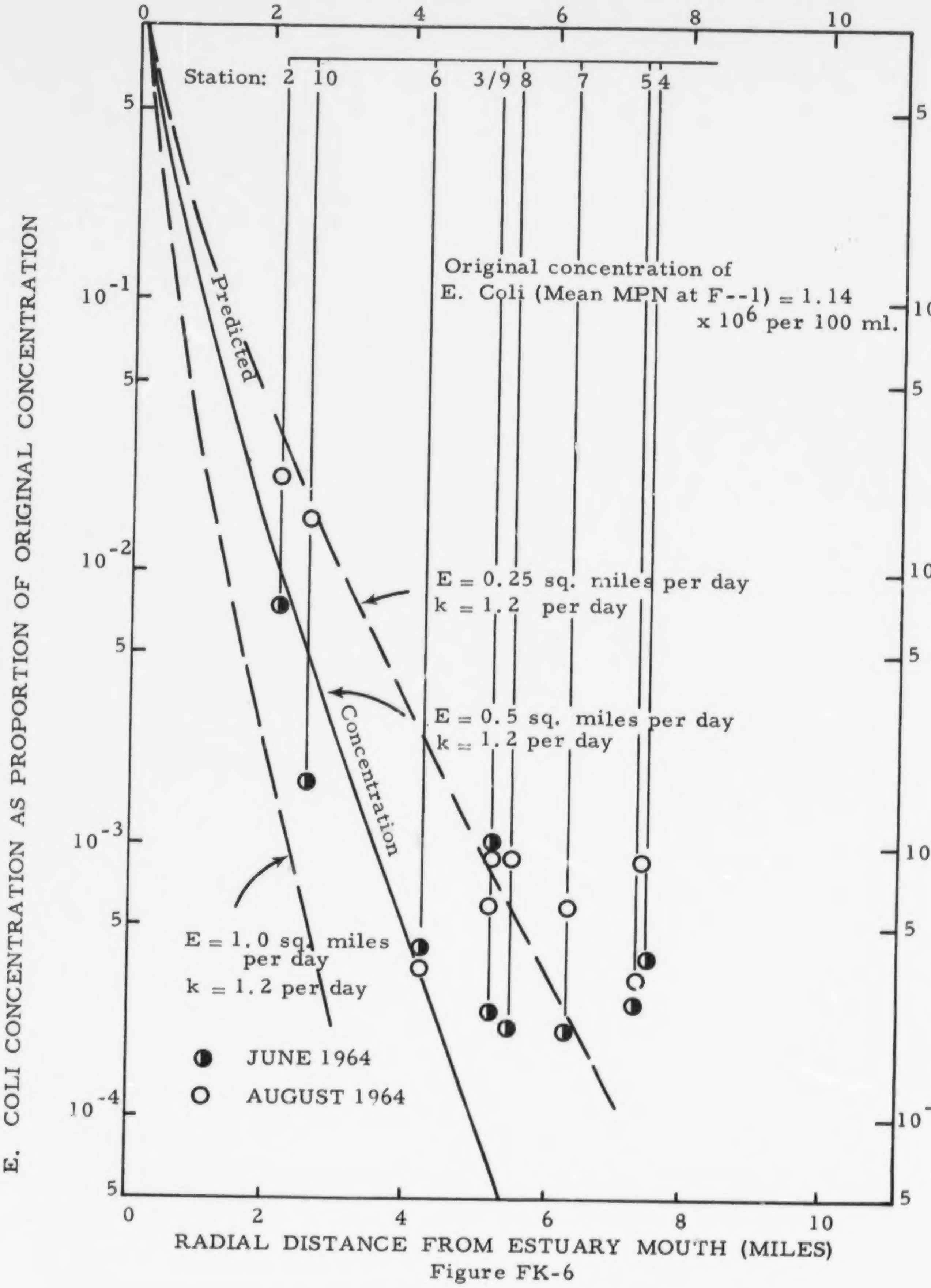


Figure FK-6

Bacterial Distribution, Gulf Waters Off the Fenholloway Estuary (Summer)

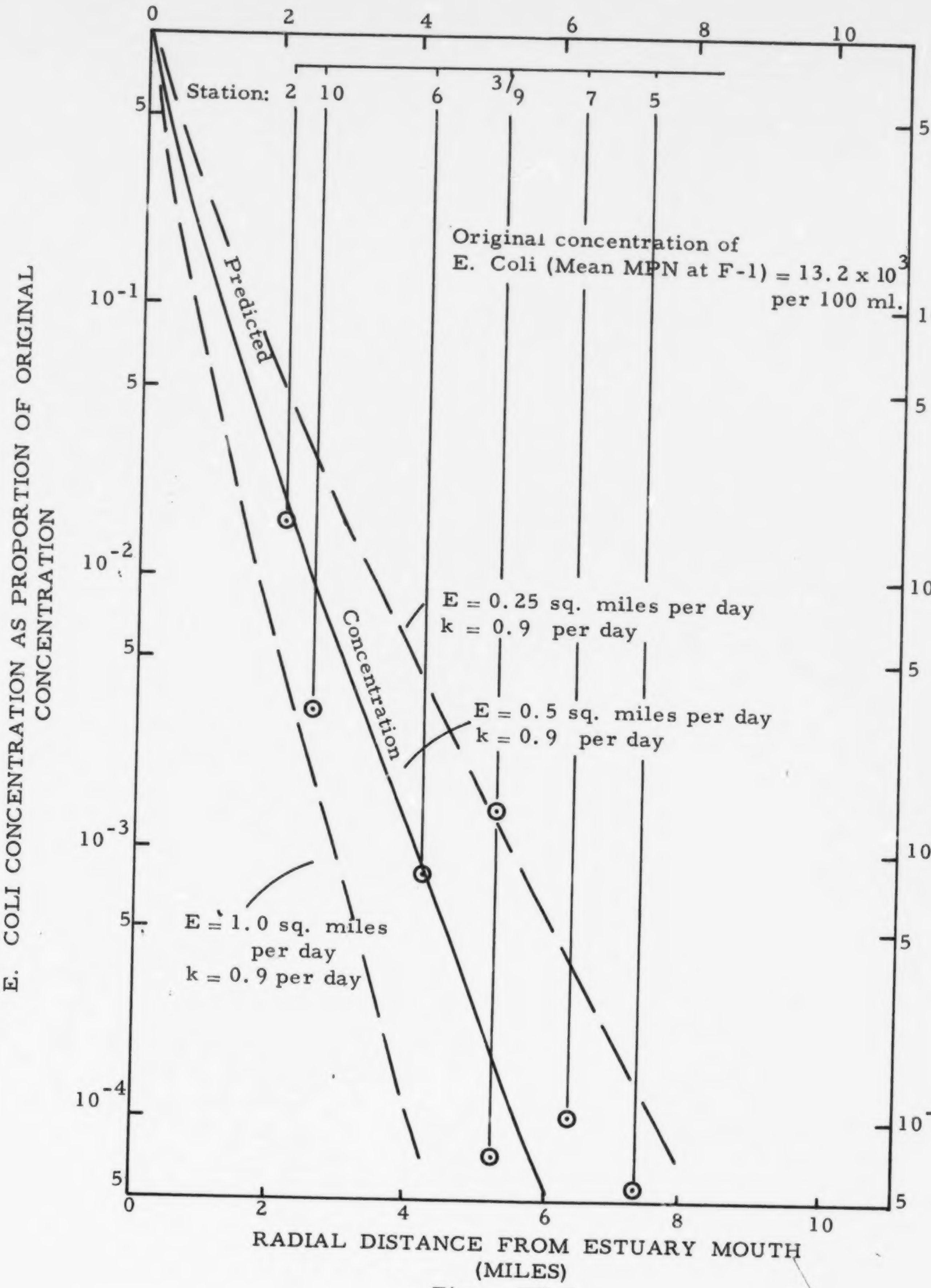


Figure FK-7

Bacterial Distribution, Gulf Waters Off the Fenholloway Estuary (Winter) where y is the fractional rate of renewal per unit time. There is always some mixing in an estuary, but complete mixing is very unlikely. The mixing in each estuary will fall somewhere between the two extremes. Tidal flow from and to the ocean or gulf will also provide additional "new" water, which results in a shorter mean residence time or half-life than that estimated on the basis of fresh water advection only.

The rate of flushing in the Fenholloway Estuary is more rapid than in the Waccasassa. For minimum monthly flows the flushing times or mean residence times of the two estuaries are estimated as:

Fenholloway (250 cfs)	0.8 days
Waccasassa (125 cfs)	4.4 days

Conclusions

1. The determination of coefficients of eddy diffusivity in estuaries often presents some difficulties. If the estuary is fairly well mixed at normal flows, the use of salinity intrusion may provide a satisfactory way of estimating eddy diffusivity. In this study estimates of diffusivity coefficients at dry weather flows from salinity data were as follows:

Waccasassa Estuary	2.0 to 2.5 square miles per day
Fenholloway Estuary	1.8 to 2.3 square miles per day

There is no significant difference in these two ranges of coefficients. Indications that the Waccasassa is less stratified than the Fenholloway at dry weather flows tend to make the coefficients found for the former seem more reliable. However, vertical homogeneity is not essential to the determination of an *effective* coefficient of horizontal eddy diffusion from the distribution of fresh water in the estuary, provided that one deals with mean values over the cross section. Two disadvantages in the use of salinity as a tracer are: (a) salt water does not enter the estuary in the same manner as pollution, and (b) the density of salt water is greater than that of most wastes encountered.

2. The use of dyes as tracers may be suitable in the river (as distinguished from bay) sections of estuaries if the advective flow is sufficiently small so that the dye can be moved back and forth in the estuary for several days, giving good lateral homogeneity without the loss of an appreciable amount of the dye mass to outside waters. The dye used should be readily detectable over a wide range of concentrations, and it is preferable that it be highly conservative. Loss through adsorption on suspended sediment of algae should be low.

3. The determination of effective coefficients of diffusivity in the shallow Gulf waters adjacent to the two estuaries involves the measurement of the rate of diffusion of dye or other tracer at a linear scale much smaller than the dimensions of the area involved in real or potential pollution. Use of an internal tracer such as salinity or fresh water is not feasible in the open water outside the estuary mouths. The coefficients found through the measurement of small dye clouds persisting for three or four hours and initiated from point sources in Waccasassa Bay and offshore from the mouth of the Fenholloway were consistent with each other and were of the same order of magnitude as those found by other investigators in similar environment.

Waccasassa Bay

$E_x = 1.5$ sq. ft. per sec. $(1.4 \times 10^3$ cm^2 per sec.)

$E_y = 0.08$ sq. ft. per sec. (72 cm^2 per second)

Fenholloway (Adjacent Gulf Waters)

$E_x = 1.6$ sq. ft. per sec. (1.5 cm^2 per sec.)

$E_y = 0.06$ sq. ft. per sec. (55 cm^2 per sec.)

For practical use these values should probably be be expanded by the $L^{4/3}$ relationship. This procedure has been used in this study for computing values of E from dye observations in waters gulfward of the estuary mouths. Further study would appear to be warranted of methods of determining eddy diffusivity at a larger scale in very shallow coastal waters such as border these two estuaries in order that the determination of diffusivity coefficients will require minimum extrapolation to be useful in practical problems of pollutant diffusion.

4. Because of its heavy load of pollution, the Fenholloway Estuary is anaerobic above the mouth under normal flow conditions except for a short distance near the mouth at the higher tide levels. The pollution entering the river becomes thoroughly mixed by the time it reaches the upper limit of tidal action. Conventional analysis dealing with oxygen depletion and reaeration is not appropriate in this situation. The relatively steep profile and short length of the estuary result in a short mean residence time, which is on the order of one-half day. Diffusion within the estuary proper under conditions of complete oxygen depletion is less significant than diffusion in the adjacent Gulf outside the mouth. The effective coefficients of diffusivity in the shallow waters of the Gulf near the mouths of both the Fenholloway and Waccasassa estuaries are approximately 0.4 to 0.5 square miles per day. During periods of high wind and wave action, these coefficients will be somewhat higher. Study of the correlation between increase in eddy diffusivity and higher wind and wave action would permit better engineering estimates of long-term diffusion and distribution of pollutants introduced into the coastal waters of the Gulf of Mexico.

5. The analysis dealing with the diminution of *E. coli* concentrations has value in estimating the probable concentrations of other pollution parameters having a known rate of decay which have been discharged into a marine coastal zone. Data on *E. coli* were readily available in in this study, but other pollutants such as pesticides and radioactive isotopes could have served as well had they been present in the river in measurable concentrations.

Appendix 1

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Appendix 2

ANALYTICAL PROCEDURES FOR DETERMINING PHYSICAL, CHEMICAL, AND BACTERIOLOGICAL PARAMETERS

CHEMICAL AND PHYSICAL DETERMINATIONS

Determinations of dissolved oxygen, biochemical oxygen demand, chloride, pH, ammonia nitrogen, total organic nitrogen, sulfate, alkalinity, orthophosphate, volatile suspended solids, color units, and turbidity units were made in accordance with the techniques presented in 11th Edition of Standard Methods (1). Salinity was computed from results of chloride determination (2), or was measured *in situ* by means of an Industrial Instrument's Model RS-5 salinometer. The salinometer was calibrated at intervals by chloride titration.

In addition to the foregoing, the following chemical determinations were made in connection with routine or extended sampling: chemical oxygen demand, nitrate, total phosphate, lignins, and Pearl-Benson lignin. The techniques used for these particular determinations are described here.

Chemical Oxygen Demand. For reasons stated in Section I, only limited COD determinations were made on the Waccasassa. For the Fenholloway, the analytical procedure followed that given in the 12th Edition of Standard Methods, although prior to publication of that edition. The later work of Cripps and Jenkins (3) presents modifications which are regarded as more suitable for saline waters. The significance of the COD determinations as recorded in the Tables of Analyses (separate Section L) is discussed briefly under FI. PHYSICAL, CHEMICAL AND BACTERIOLOGICAL ANALYSES.

Nitrate. In the determination of NO_3^-N, the usual phenol-disulphonic acid method was used for non-saline waters (1). For saline waters, two methods were used, with only partial success. In one method, nitrates were determined by reduction to ammonia, followed by distillation of the ammonia and Nesslerization.

A modified brucine technique was finally adopted, as described in "Brucine Method for the Determination of Nitrates in Ocean, Estuarine, and Fresh Water" by Jenkins and Medaker, Analytical Chemistry, Vol. 36, No. 3, pp. 610-612, March, 1964. Results with this test were somewhat unsatisfactory since again these lacked both accuracy and precision. However, the brucine method, which has a minimum reliable sensitivity of <0.5 mg/1, as with all others studied, indicated low NO_3 values consistently, confirming earlier conclusions that nitrate concentrations were generally low in the saline waters studied.

Total Phosphate. The method used for determination of total PO_4 is given in detail.

I. Apparatus.

  A. Acid-washed glassware. Glassware should be cleaned with hot dilute HCl and rinsed well with distilled water.

  B. Spectrophotometer, Beckman D.U.; for use at 690 $m\mu$.

II. Reagents.

- A. Phenolphthalein indicator solution: Dissolve 5 gm. phenolphthalein in 500 ml. 95 per cent ethyl or isopropyl alcohol and add 500 ml distilled water.
- B. Strong acid solution. Slowly add 300 ml conc. H_2SO_4 to about 600 ml distilled water. When cool, add 4.0 ml conc. HNO_3 and dilute to one liter.
- C. Ammonium molybdate – strong acid solution (1): Dissolve 25 g $(NH_4)6\ Mo_7O_{24}\ 4H_2O$ in 175 ml distilled water. Cautiously add 280 ml conc. H_2SO_4 to 400 ml distilled water. Cool, add the molybdate solution, and dilute to one liter.
- D. Stannous chloride solution (1): Dissolve 2.5 g of fresh supply of $SnCl_2 \cdot 2H_2O$ in 10 ml with distilled water. Filter if turbid. Place in an aspirator bottle having a glass stopcock. Add a layer of pure mineral oil 5 mm thick over the surface of the solution to minimize oxidation. Always drain a little of the solution out of the stopcock before use. The reagent can be preserved for several weeks by adding mossy tin and storing in a refrigerator.
- E. Stock phosphate solution: Dissolve in distilled water 0.7165 g potassium dihydrogen phosphate, KH_2PO_4, which has been dried in an oven at 105°C. Dilute the solution to 1,000 ml; 1.00 ml = mg PO_4.
- F. Working phosphate solution: Dilute 100.0 ml stock phosphate solution to 1,000 ml with distilled water. This solution contains 0.050 mg PO_4 per 1.00 ml.

III. Procedure. Pipet 100.0 ml of sample containing not more than 1.5 mg PO_4 into a clean, dry evaporating dish. Place in 105°C drying oven and evaporate to dryness. Then heat the dried sample at 600°C for 1/2 hour. The resultant sample is then digested by adding 3-5 ml of conc. HNO_3 and washing down the sides of the dish with distilled water.

Again the sample is heated to dryness and then taken up with 1-2 N HCl washed with 100 ml distilled H_2O.

One drop of phenolphthalein is then added to the acidic solution. Add 1 N NaOH dropwise to the sample until a pink color develops and then add strong-acid solution dropwise to discharge the color.

Add with thorough mixing after each addition, 4.0 ml molybdate (1) solution and 0.5 ml (10 drops stannous chloride solution (1). All samples are kept within 2°C of one another and at a temperature of 20°- 30°C.

After ten minutes, but before twelve minutes, employing the same specific interval for all determinations, measure the color photometrically at 690 ml and compare with a calibration curve, using a distilled water blank. A blank must always be run on reagents and distilled water.

Pearl- Benson Lignin. The Pearl-Benson, or nitroso, method is based upon the reaction of phenolic groups in lignin with nitrite in acidic solution to form nitroso derivatives which in alkaline solution yield highly colored quinone oxime derivatives. Pearl and Benson first used visual methods for estimation of the color intensity thus generated by spent sulfite liquor (lignin sulfonates) in fresh or salt waters (4). In addition to lignin sulfonates, phenols such as kraft lignins and tannins can react in the nitroso method. Based upon recent recommendations by Barnes, et al. (5), a method was selected for the estimation of lignins of kraft mill origin in fresh and saline waters.

Estimation of Kraft Lignin by a Pearl-Benson, or Nitroso, Method

I. Reagents.

- A. 10 per cent Acetic Acid, V/V.
- B. 10 per cent Sodium Nitrite: 10 g of reagent $NaNO_2$ to 100 ml total volume with distilled water. Store in glass-stoppered bottle.
- C. 2_N Ammonia: dilute 135 ml 28 per cent NH_3 (ammonium hydroxide) to 1000 ml with distilled water. Store in Pyrex or borosilicate glass bottle.

(The reagents should be tested for purity by measuring blanks with both normal and twice the normal reagent volumes.)

II. Apparatus

Beckman Model DU spectrophotometer, with 10-cm path length.

III. Preparation of Samples.

Settle for 12-24 hours or filter through a millipore filter.

IV. Definitions.

A_T, the total absorbance. Comprises the absorbance of the nitroso reaction products, the absorbance of the natural water sample, the absorbance of the reagents, plus any side effects (e.g., precipitate formation).

A_B, the blank absorbance. Comprises optical difference, natural water sample absorbance, and absorbance of the reagents.

V. Evaluation of A_T, the total absorbance.

A. Measure 50 ml of the prepared sample into a 125-ml Erlenmeyer flask.
B. Add 1 ml of 10 per cent acetic acid and 1 ml of 10 per cent sodium nitrite. Mix thoroughly by swirling; allow to stand for 15 minutes at room temperature.
C. Add 2 ml of 2N ammonia, mix and let stand for 10 minutes at room temperature.
D. Measure A_T at 430 mμ with respect to distilled water.

VI. Evaluation of A_B, the blank absorbance.

A. Measure 50 ml of the prepared sample into a 125-ml Erlenmeyer flask.
B. Add 1 ml of 10 per cent acetic acid. Mix thoroughly.
C. Add 2 ml of 2N ammonia, and mix again.
D. Add 1 ml of 10 per cent sodium nitrite, mix thoroughly and allow to stand 10 minutes.
E. Measure A_B at 430 mμ with respect to distilled water.

VII. Net Absorbance, $A_S = A_T - A_B$.

This is the absorbance due to the nitroso reaction product, and may be expected to bear a linear relationship to the concentration of kraft lignin in the sample.

Application to Fenholloway Area Water Samples. A nearly-pure non-sulfonated lignin* was employed to establish a relationship between the weight-volume concentration of lignin material and the net absorbance, as measured in the foregoing method. A satisfactory linear calibration was obtained over the range of lignin (Indulin C) concentration from zero to 100 mg/l (1-cm and 10-cm cell path, as required). Typical results obtained in a preliminary evaluation of the method are shown in the following table.

SOME TYPICAL RESULTS FROM PEARL-BENSON LIGNIN METHOD

Filtered* Sample† Solution	A_S 1-cm	Apparent P-B Lignin mg/l
Indulin C	0.29	100
Indulin C	0.03	10
Lagooned kraft mill effluent	0.13	45
Station F-101	0.02	7
Station F-109	0.026	9
Station F-2	0.007	2

*100 mμ millipore filter
†River and nearshore Gulf samples collected in December, 1964

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*Indulin C, a product of West Birginia Pulp and Paper, Chemical Division, is a sodium salt of a naturally occurring polymer produced from wood, containing about 10 per cent sodium. It is reported to be completely free of wood sugars and similar degradation products.

Lignin

This estimation of lignin-like substances in water was made using the Model TA-1 Tannin and Lignin Test Kit available from Hack Chemical Company, P. O. Box 907, Ames, Iowa. The procedure can be described briefly as follows: Production of colored complex within the sample, and comparison with known standards.

Results obtained with this test procedure generally paralleled those obtained by the Pearl-Benson procedure, although the particular tannin-lignin method used was not so sensitive as the Pearl-Benson procedure.

BACTERIOLOGICAL DETERMINATIONS

Techniques. In order to obtain the maximum information concerning pollution and bacterial densities, determinations of the Most Probable Number Index of the total coliform group and the Standard Plate Count were considered of basic importance, and these tests were performed on all samples.

The dilution technique as given in Standard Methods for the Examination of Water and Wastewater (1) employing lactose broth for the presumptive test and Brilliant Green Bile broth for the confirmed test was used. Five portions of each of a series of multiple portions of various volumes of sample were examined. The exact volumes were varied as continued experience dictated in order that a series tested would yield both positive and negative findings, thus permitting computation of the M.P.N. Index per 100 ml.

Initially, duplicate portions of each sample were also examined by the Membrane Filter Test, using both LES Endo medium and M Endo medium. Varying volumes of sample, diluted to 100 ml with buffered dilution water were used and examined in duplicate. Experience soon indicated that reliable determinations of bacteria of the coliform group could not be obtained due to the excessive number of non-coliform bacteria present in most samples and which tended to obscure the coliform colonies on the filter surface. Thus the use of this particular technique was discontinued early in the study. The Standard Plate Count was made on all samples, again using a volume of each sample which experience and previous observation indicated to yield a count per plate between 30 and 300 colonies. For this test, plate count agar was employed with incubation at 35°C for 24 hours.

Because of the potential significance of those members of the coliform group developing favorably at higher temperatures (45°C), additional determinations of the relative density of these bacteria were included. There is ample evidence available indicating that this particular section of the coliform group has its origin in the intestinal discharges of warm-blooded animals, and therefore it is a more definitive measure of fresh and significant pollution than the total coliform group. For this test, duplicate portions of each positive presumptive tube were transferred to the confirmatory Brilliant Green Bile broth, one being incubated at 35°C and the other at 45°C. Positive findings in the 45°C incubation test were considered to indicate that the presumptive positive findings were due in part to the presence of members of the so-called fecal section of the coliform group in the volume of the sample examined. Thus, two M.P.N. Indexes were obtained.

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Appendix 3

GLOSSARIES

PRIMARY PRODUCTIVITY

Algal Photosynthesis: the process carried out by phytoplankton whereby simple carbon compounds in the environment are reduced and incorporated into the cell as simple sugars. The process is carried out by various plant pigments in the cell which are activated by light. The end product of this activity is gaseous oxygen.

Allochthonous: arising within another biotope.

Autochthonous: arising within the biotope under consideration.

Autotrophic: a type of nutrition where inorganic substances are substrates for organisms to synthesize organic molecules. The process literally means self-nourishing and is carried out by a number of aquatic microorganisms including many bacteria and algae.

Benthic: One of the primary divisions of the sea which includes all of the ocean flow. It also includes the bottom area submerged at flood tide.

Bioassay: a determination of the presence or absence of a substance in the environment by the use of a biological system. By refined techniques, this method may be quantitative as well as qualitative. The determination of the concentration of a given material is made by a comparison with a standard preparation. In this report phytoplankton were used as the test system.

Biocoenosis: a community of organisms whose composition is determined by the properties of the environment and by the realtions of the organisms to each other.

Biosphere: that part of the earth containing living organisms

Biotope: an area where the principal habitat conditions and the living forms which are adapted to them are uniform.

Chemosynthesis: the synthesis of organic matter from mineral substances with the aid of chemical energy.

Chromatophores: the pigmented bodies found in plant cells and consisting of protoplasmic material and which can be activated by sunlight in the photosynthetic process.

Detritus: organic particulates consisting of plant material plus bacteria. It is usually microscopic in nature and and is a stage in the decomposition of plant and animal materials.

Ecology: the scientific study of the relations between organisms and their environment.

Epiphytes: plants that are not rooted in the bottom but rather use other plants as a substrate without penetrating into them and without withdrawing nutrient substances from them.

Euphotic Zone: the layer of the oceans where the net rate of photosynthesis of phytoplankton is positive. The depth of this zone is governed mainly by the mean amount of solar radiation and the optical properties of the water.

Eutrophic: literally meaning true food, the term has come to be used to signify the maturing or aging process of a body of water. The acceleration of the aging process brought about by overfertilization of water systems by man's activities is called cultural eutrophication.

Heterotrophic (other nourishing); a type of nutrition where organisms must rely upon organic molecules in some form to supply energy. Usually this is accomplished by the decomposition of complex materials which are found in the environment.

Milli Special Pigment Units: an artificial unit very close to a milligram in weight and used in designating the amount of plant pigment other than chlorophyll *a* and *b*.

Morphology: the study of configuration or form.

Morphometry: a study of the form of a basin usually containing fresh water. Among the physical characteristics included in a study of this kind are: area, mean area, mean depth, volume.

Nannoplankton: this term is used to indicate a general size range of organisms approximately 10-50 microns for the largest dimension.

Nearctic Region: the zoogeographic region of the world which includes the North American continent.

Nekton: animals that swim freely by their own efforts. This includes larger forms such as fish and turtles.

Neritic: this is known as a subdivision of the pelagic area of the sea. The neritic province extends outward from the shore to the edge of the continental shelf. Therefore water less than 200 meters in depth is within the neritic zone.

Netplankton: this term is used to denote those organisms which would be retained in a plankton net consisting of number 25 mesh silk bolting cloth.

Oceanic Zone: includes all those areas of the sea deeper than 200 meters.

Oligotrophic: water which has a very small amount of nutrient material and therefore has a limited fertility.

Pelagic: the primary division of the sea which includes the water mass.

Plankton: the free assemblage of plants and animals which are microscopic and near microscopic in size and which float and draft freely in the water under the influence of waves, currents, and other water motion.

Standing Crop: the density of organisms, either plant or animal, which is present at a given period of time.

See also *Glossary of Commonly Used Biological and Related Terms in Water and Waste Water Control.* Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio. 1963.

DIFFUSION AND POLLUTION ASSIMILATION

Advective Flow: net horizontal flow in one direction (as distinguished from oscillating tidal flow).

Diffusion, Turbulent: the process of translation of particles in a medium from regions of higher concentration to lower ones by random processes, principally eddies of turbulence.

Estuary: a semi-enclosed coastal body of water with a free connection to the sea and with measurable dilution of sea water by fresh water drainage.

Eddy Diffusivity: the rate of transfer of a dissolved or suspended substance across a unit area divided by the concentration gradient along a line normal to that unit area. It has the dimensions of area divided by time or length divided by velocity (L^2/T). The term is used interchangeably with coefficient of eddy diffusivity and diffusion coefficient in this and other reports.

Exchange Coefficient: the rate of renewal of the water of an estuary by water particles not previously resident therein.

Flushing Time (also mean residence time or detention time): the average length of time required for a particle introduced into an estuary to pass through the estuary to the open sea.

Half-life: the time interval required to replace one-half of the water resident in an estuary at any given time by new water particles.

Mean Tide Level Volume: the volume of an estuary below the mean tide level.

Stratification: the degree to which an estuary exhibits high vertical gradients of salinity or density; interfaces or discontinuities of salinity or density distribution are characteristic of high degrees of stratification.

Tidal Prism: the total volume of sea water exchanged between an estuary and the open sea in the interval between high and low tide.

Tracer, Conservative: a tracer whose concentration in a medium is not a function of decay (such as photochemical, radioactive, etc.), but is dependent only on dilution by particles of the medium under the influence of hydrodynamic processes (such as chlorides, dye, etc.).

Tracer, External: a material introduced into a medium which is capable of being freely dispersed throughout the medium and detected quantitatively.

Tracer, Internal: a component or quality of a medium occurring in the natural state and capable of being detected quantitatively.

Tracer, Non-Conservative: a tracer whose concentration decreases with time, independently of the hydrodynamic processes within the medium.